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FUNGOUS DISEASES OF PLANTS

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FUNGOUS DISEASES OF PLANTS

WITH CHAPTERS ON

PHYSIOLOGY, CULTURE METHODS AND TECHNIQUE

BY

BENJAMIN MINGE DUGGAR

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PREFACE

It is a noteworthy fact that there has been available to student and reader no general text or reference book of American origin upon fungous diseases of plants. Nevertheless, for thirty years or more there has been active investigation in this field, and during much of this time instruction in plant pathology has been an important part of biological teaching in all colleges where plant industry or country-life interests have been adequately represented. In the agricultural colleges the teaching of general mycology has been important, and that of plant pathology is now essential. The presentation should be fundamental, but it should also bear a close relation to the affairs of life. Plant pathological work has been rapidly developed in all countries characterized by a progressive agriculture, and for European conditions the student experiences no great lack of reference works.

Through the agricultural experiment stations and through the extension work in various states a vast amount of information with respect to plant diseases has been published and otherwise disseminated, so that to every intelligent plant producer the opportunity has been extended of becoming more familiar with the crop relations of destructive parasitic fungi. The student and the progressive grower require something further, and it has therefore seemed none too early to put in book form a comprehensive discussion of the chief fungous diseases of cultivated and familiar plants. It is not intended that this book shall be an introduction to systematic mycology; yet the arrangement of the material in taxonomic sequence with respect to the fungi largely eliminates the necessity of any mycological preparation as a prerequisite.

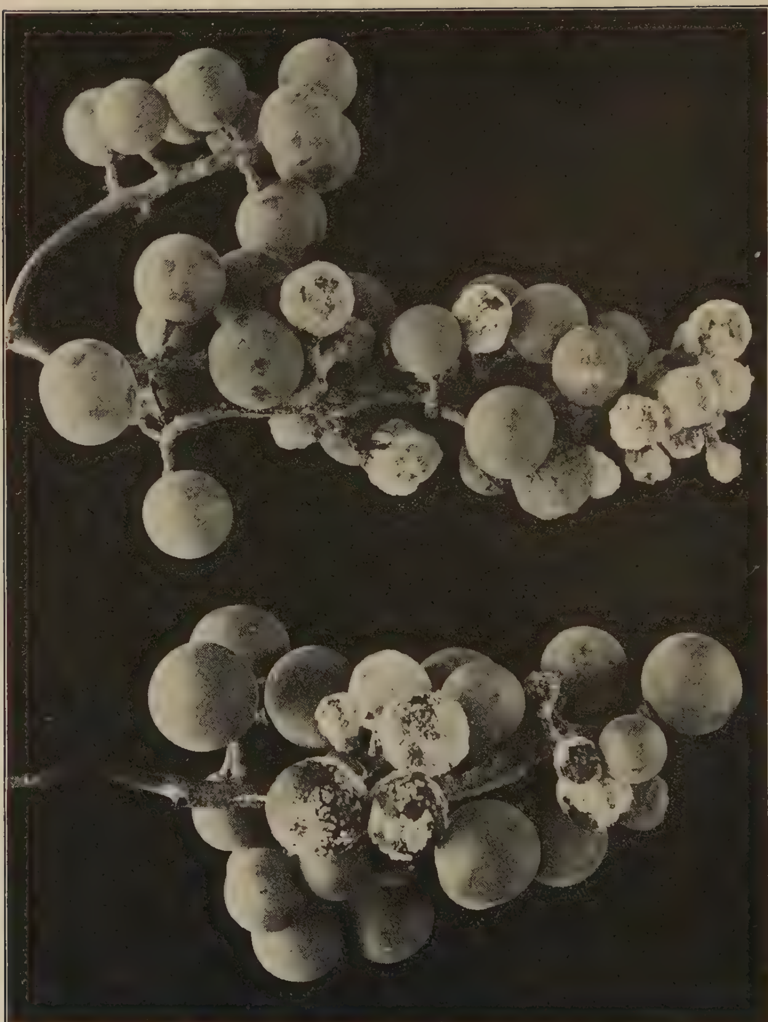
As far as practicable, in the discussion of each disease, three important considerations have been kept in view: (1) to describe the pathological effects and other relations of host and parasite;

(2) to make clear the life history of the causal fungus; and (3) to indicate the approved or suggested methods of prevention or control. The author fully recognizes that in any complete discussion of a fungous disease there are definite theoretical subdivisions, such as symptoms, pathological morphology, etiology, life cycle of the causal organism, etc. Nevertheless, such a system does not at present recommend itself. In the nomenclature of popular names of diseases uniformity, or special fitness, at a sacrifice of established usage, has been avoided. An extensive host index has been included in order to present in a succinct form all of the diseases discussed upon any host. It is, perhaps, needless to add that the chapters upon culture methods, technique, and physiological relations are designed primarily for reference, and to stimulate the most complete use of the available material. The bibliography is intended to be suggestive, and the titles are made prominent that the suggestion may not be avoided.

Aside from photographs and drawings made by the author, the illustrations have been derived from a variety of sources. Special acknowledgment is made to Mr. F. C. Stewart, of the New York Agricultural Experiment Station, and to Professors H. H. Whetzel and George F. Atkinson, of Cornell University, for the privilege of using many negatives from their collections. Many others have kindly furnished material for one or more illustrations, as credited in the legends. In the preparation of the drawings much assistance has been given by Mrs. B. M. Duggar. For helpful suggestions respecting the manuscript and for a first draft of the synopsis of species among the Uredinales, the writer is indebted to Professor George M. Reed, of the University of Missouri.

B. M. DUGGAR

CONTENTS



Downy Mildew on Niagara Grapes

FUNGOUS DISEASES OF PLANTS

INTRODUCTION

A proper study of the fungous diseases of plants is at once scientific and practical. The fungi were carefully studied, however, long before their importance as disease-producing organisms was recognized. A history of our knowledge of the fungi in general, therefore, takes us through periods when the scientific and the practical attitudes were not associated; yet a brief historical survey must develop important and interesting facts bearing upon the relations of scientific work to practical affairs.

Systematic mycology. A careful study of the fungi as independent groups of plants was begun in the latter part of the eighteenth century, and if we examine the results of the work beginning at that time and continuing into the early half of the nineteenth century, it will be found that this period was one of most accurate and painstaking endeavor in systematic mycology. Much credit is therefore due to the more prominent students of that time, such as Bulliard, Persoon, Nees von Esenbeck, Schweinitz, Léveillé, Fries, and Berkeley. The work so well begun was continued into the second half of the same century, and among the names particularly associated with that period are those of Fuckel, Karsten, the Tulasne brothers, Corda, and many others. This systematic study has, of course, continued to the present time, although the nature of the work produced has undergone important changes. Two phases in the modern development of this systematic work are well shown by the appearance, on the one hand, of Saccardo's monumental "Sylloge," and, on the other hand, of such complete morphological monographs as Thaxter's "Laboulbeniaceæ."

Physiology and morphology. The progress in systematic mycology has made possible for more than half a century a comprehensive study of the diseases of plants; yet systematic study alone is not responsible for the rapid progress subsequently achieved in plant pathology. A number of causes might be suggested as of importance in the development of the latter field. It should not be overlooked that advances in general plant physiology were also manifest at about the beginning of the nineteenth century, and that this phase of botany had undergone unusual development toward the middle of the century, under the influence of Sachs and other experimentalists of his time. Again, a more intensive method in the study of morphology had been introduced, and in mycology the efforts of such men as the Tulasne brothers had shown what could be done in carefully following out the life histories or development of the fungi. Beginning about the middle of the nineteenth century, another distinctive epoch is entered upon, and the developments of this period are due chiefly to Anton de Bary and his contemporaries.

The rise of plant pathology. De Bary became the conspicuous leader in this field, establishing in an incontrovertible manner the connection between the polymorphic stages of certain parasitic species, and the possibility of following, under well-controlled conditions, the development of little-known groups. His work was, furthermore, particularly significant in that he so thoroughly appreciated the nature of parasitism, the epidemic character of fungous diseases of plants, and the practical value of methods of inoculation and infection. To him more than to any one else we owe the influence which directed future work along the lines of the most profitable research. This period witnessed also the advances made by Pasteur and others in the study of fermentation and disease, and it was closely followed by those perfections in the development of pure culture methods which have finally resulted in the possibility of cultivating practically all bacteria and a very great majority of the fungi. In the study of the fungi as the cause of plant diseases, at this time, valuable service was also done by Kühn, who in his early career devoted himself particularly to a study of the fungous parasites of cultivated plants. The last decades of the century yield work of such diversity and importance that it is impossible here to

do more than make briefest reference to it. The work of Brefeld is perhaps most distinctive, and while his theoretical views have not had a host of followers, his fundamental studies in the general field of mycology, and particularly, in this connection, his wide range of experiments in the artificial cultivation of organisms, are invaluable. Among many others who contributed special service in some phase of pathological or general mycological work of that time may be mentioned also Frank, Hartig, Schroeter, Sorauer, and Winter in Germany; Oudemans in Holland; Cornu, Millardet, and Prillieux in France; Comes in Italy; Woronin in Russia; Eriksson in Scandinavia; Plowright and Ward in England; Farlow, Burrill, and many others in the United States. The work has continued vigorously, investigations and problems have multiplied, and with adequate conservatism the outlook is most encouraging.

There were some indications of a plant pathology in existence from the time of the first studies in systematic mycology, but an examination of the books which purport to be discussions of plant pathology shows that they were in large part an attempt to classify and suggest ideas having to do with plant diseases, after the manner of the older attempts which were made in human medicine. In most cases the life history of the organism which caused the disease was entirely unknown; and, in fact, there is no plant pathology which deserves the name affixed to it prior to the appearance of Kühn's "Die Krankheiten der Kulturgewächse," Berlin, 1858. Between that time and 1900 an extensive literature developed. The status of the morphological work is well shown by De Bary's "Morphologie und Biologie der Pilze," etc., and in addition to many special life-history or monographic studies we have, from the pathological point of view, such comprehensive reference books as those of Comes, Frank, Hartig, Prillieux, Sorauer, Tubeuf, Ward, and others.

Practical pathology and disease control. An important epoch in the general study of fungous diseases had its beginning in the prevalence of grape diseases in France, which condition led to the discovery of Bordeaux mixture by Millardet in France about 1883. After the severe tests to which the copper mixtures were subjected, it became evident that there was a bright prospect for controlling many of the fungous diseases of plants, and there developed therefore an immediate need for plant pathologists, or students of fungous

diseases of plants, — persons who should be, at the same time, appreciative of the problems of disease control. Incidentally it may be noted that plant diseases were, for the most part, understood to be of fungous origin. In the United States this was more or less coincident with the organization of a section of Plant Pathology in what was then the Division of Botany at Washington, and with the development of plant pathological work in many of the state experiment stations. In a very short time there was unusual activity in this study throughout the country. There was also much stimulus to the further development of the work in Europe, and the outcome was that the foundations were laid for a more careful study of the fungi from a phytopathological point of view. In this country the work was directed more especially toward immediately practical ends, and that which was accomplished within a brief period of time through the efforts initiated by Scribner and Galloway was remarkable. In more recent times the work has also been put upon a higher plane, and investigations along broader and more fundamental lines have gone forward rapidly at many points throughout the country, so that to-day the extent of the organization and equipment for research in this field is better than may be found anywhere else in the world. It is perhaps fortunate that this work in the United States has developed in conjunction with the agricultural experiment stations, although, when the equipment in men, books, and apparatus was new, many mistakes were made. This association of the work insures that the direction of it will be at least more practical than if confined more or less to investigations carried on in botanical gardens or herbaria. It is perhaps to be regretted that there cannot be more unity of action, or coöperation, in the study and control of epidemic diseases. This, however, may be brought about in the course of time.

Some aspects of modern plant pathology. It is very evident from the nature of the study, as well as from the historical notes which have been presented, that an analysis of the modern work in plant diseases indicates several important aspects, which may be grouped in the following category: (1) mycological relations; (2) anatomical effects; (3) physiological relations; (4) control measures.

Mycological relations. The mycological aspect will be concerned more particularly with a minute investigation of the fungi from

systematic, morphological, and physiological standpoints. Too often, in the early work, the chief object of the study has been to identify the fungus associated with a given disease and to describe its fruiting stages. An investigation of the fungus, however, should include an account of its complete life history wherever possible, the relations of the fungus to conditions under which it is injurious, the character of the growth produced upon various culture media (when the organism is culturable), the conditions under which fruiting stages may be developed, etc. In the course of time, therefore, it will be necessary to repeat much of the work of earlier date, which has seemed to be more or less complete.

Anatomical effects. The anatomical study, in the sense in which it is here used, will be concerned with the relations of the host to the parasite, in so far as the former may be modified in growth or minute structure. All lesions, hypertrophies, or other structural changes produced in the host plant are worthy of the closest attention. These changes in the host are most diverse, varying, on the one hand, from minute modifications of a single cell, or of a small group of cells, to those changes of form which involve an immense increase in the size of the host organism, often giving rise to relatively enormous deformities, such as may be noted in the case of the club root of cabbage, plum pockets, cankers, and smut of corn. Again, the deformities may result in the pushing into growth of an abnormal number of buds, in many instances accompanied by decreased size of the branches and changes in the trophic relations, such as to develop the various forms of witches' brooms. The anatomical changes[1] in the host are those most commonly termed pathological changes. Unfortunately these are often discussed as if they were the only pathological effects. They are, at any rate, the chief evident pathological effects in many cases, and for that reason they constitute in the popular view that which is properly designated "plant pathology."

Physiological relations. In close connection with the anatomical changes produced in the host, a study should be made of the physiological relations of host and parasite, particularly of the

[1] Küster (Pathologische Pflanzenanatomie, 312 pp., 121 figs., 1903) has attempted a general classification of anatomical modifications induced by diverse stimuli.

physiological disturbances in the host itself.[1] The normal physiology of the host requires attention in order that a proper comparative study may be made. The conditions which predispose the host plant to attack, or, in other words, the conditions favorable to the penetration of the fungus and its development within the host are most fundamental from the standpoint of pathology, and also in order that control measures may be properly developed. It is a direction in which future work promises most profitable returns. Very little of lasting value has been done towards determining the exact conditions under which the host plant is most susceptible to attack. It is well known in the case of certain forced plants that the undue suffusion of the plant with water, whether due to lack of ventilation or to a combination of causes, is a certain factor in inducing disease. Under such conditions many fungi are able to gain entrance and become the cause of epidemics, whereas, under more normal conditions, they may remain as harmless inhabitants of dead materials.

Every season shows differences in the prevalence of the more injurious fungous diseases. One season the brown rot of the peach may affect only extremely sensitive varieties, and the following season it may cause the loss of those most resistant. Again, some varieties of the host may be, under most conditions, but slightly predisposed to attack, notable instances being those of the very slight predisposition of the Kieffer pear to the blight, or in the resistance of certain American varieties of grapes to the downy mildew. Such cases might be multiplied indefinitely, and, in fact, there is scarcely a known fungous disease of the variable cultivated crops with reference to which all varieties of the host plant are equally susceptible. This important fact has led to the selection and to the production through hybridization of varieties which shall at once possess both the qualities desired from the standpoint of their own fruits or other products, and which shall, at the same time, carry with them the high resistance necessary to enable them to compete with the fungous pests.

The effect of the fungus upon the host may be, further, merely to modify the quality of the product, such as the sugar or starch content, without seriously affecting the appearance of the economic product. In fact, the different means whereby the effect of the

[1] See Ward, H. M., Disease in Plants, 1901.

fungus may show itself in slight physiological disturbances of the host are too numerous for special consideration.

Control measures. Control measures for the prevention of fungous diseases should be a part of every study which is undertaken. Reference has already been made to the very rapid development of systematic methods of control. Control may be developed along one or more very different lines. In the first place, it may concern itself more particularly with a maintenance of the host plant in a thoroughly sanitary environment, or in one which renders it more resistant to the attacks of fungi. It may again concern itself with the application of deleterious substances (fungicides) to the host, in order that the germination and growth of the fungous spores may be prevented. This use of fungicides may take the form of disinfection of the seed or of propagative parts, the application of reagents to the soil in order to prevent the growth of the fungus in the vicinity of the host plant, or the application of fungicides to the aërial vegetative portions of the host, which is commonly accomplished by the operation of spraying. This latter operation has been practiced to a considerable extent for a long period of time, but the really substantial development of the work began with the discovery of Bordeaux mixture, to which reference has already been made. At the present time a great variety of spraying mixtures are employed, a large number of which contain copper compounds, or copper combined with lime, subsequently discussed in detail. There are, however, a great many directions in which the development of desirable fungicides may yet go forward. At the present time the use of lime-sulfur washes and sprays is rapidly taking an important place. It is particularly in connection with control measures, or facts concerning the life history of the organism suggesting such measures, therefore, that the study of fungous diseases of plants makes for itself a place among practical sciences. The amount of injury annually suffered by the various crops, due to fungous diseases, may be more or less definitely ascertained, and this represents the possibilities to which control work may be pushed. On the other hand, the relation of the crop in unsprayed regions to that in regions where spraying is used may permit one more or less roughly to determine the actual saving through the present imperfect and rather haphazard practice of control measures. Estimates

which have been placed upon the damage caused by prevalent plant diseases during a single season amount frequently to a very considerable per cent of the total value of the crops. In the United States alone the destruction wrought by fungous diseases is sometimes not far from half a billion dollars.

The diseases of plants induced by other biological, physical, chemical, or mechanical agencies are not included. The lack of plant nutrients, or the presence of particular nutrients in quantities sufficient to cause injury, the phenomena commonly termed sunscalds, wind effects, abrasions due to contact, etc. are all disturbances which demand attention, but they may have no definite relation to epidemic fungous diseases, and would therefore be fundamentally considered only in a general treatise on plant pathology. On the other hand, it is felt that in connection with any account of the fungous diseases of plants it is desirable to place within easy reach of the student certain related information. In isolated chapters, therefore, there is presented a brief review of culture methods, histological technique, and such facts of physiological significance as seem requisite.

Culture methods are here concerned with the essential steps in preparing important nutrient media and means for the isolation and study of fungi in artificial cultures. Such cultures are important in morphological and physiological study, and they afford in the majority of cases the only proper source of spores or mycelium for inoculation purposes.

Histological technique is requisite not merely to insure a proper morphological study of a fungus and its distribution in the host, but also in order to make possible a more comprehensive analysis of the tissue modifications in the host.

A discussion of special biological or physiological relations has been limited to a few topics. The germination of spores is from the outset one of the investigational or routine duties of the pathologist; the relations of the fungi to chief environmental factors cannot be disregarded; artificial infection is required in determining the causal organism; and the principles of disease control are concerned with the immediate application of pathological study to economic purposes.

PART I

CULTURE METHODS AND TECHNIQUE

CHAPTER I

ISOLATION AND PURE-CULTURE METHODS

LOEFFLER, FR. Vorlesungen über die geschichtliche Entwickelung der Lehre von den Bakterien **1**: 252 pp. *3 pls.* *37 figs.* 1887. Leipzig.
SMITH, ERW. F. Bacteria in Relation to Plant Diseases. Carnegie Inst. of Washington, Publication **27** (Vol. I): 285 pp. *31 pls.* *145 figs.* 1905.
(Text-Books and Manuals of Bacteriology.) Nearly all texts on general bacteriology devote considerable space to methods of culture work.

FIG. I. VIEW IN LABORATORY EQUIPPED FOR PLANT PHYSIOLOGY AND PATHOLOGY. (Photograph by O. Butler)

The student who is interested in the fungous diseases of plants will find it desirable at the outset to acquire a knowledge of pure-culture methods. The investigator in plant pathology can only proceed confidently in his work when he has had practical training in

the cultivation of fungi in the laboratory. This work has become increasingly more important in recent years. Laboratory culture methods were not generally applied to a study of the filamentous fungi until some years after bacteriology had been revolutionized by a series of important discoveries in this line of technique. It is at once evident that the bacteria could never be studied advantageously except through the establishment of pure-culture methods, whereas the larger fungi were to the early systematists and morphologists, organisms to be studied after the method applied to the higher plants and animals. Prior to the new era in bacteriology special methods were employed, it is true, in the germination of fungous spores, and some notable experiments in artificial infection had been made. Nevertheless, after the introduction of pure-culture methods in general bacteriological work had become well established, plant pathologists were not slow to appropriate and, in certain directions, to develop a technique which promised and which has served to throw open the whole field of phytopathology to research of a high order.

I. THE DEVELOPMENT AND APPLICATION OF CULTURE METHODS

NOTE. The following are some papers of interest in connection with the early development of culture methods.

KLEBS, E. Beiträge zur Kenntniss der Micrococcen. Arch. f. Exp. Path. u. Pharmakol **1**: 31–64. 1873.

COHN, F. Untersuch. über Bacterien. Beiträge zur Biol. der Pflanzen **2**: 240–276. 1876.

LISTER, JOS. On the Lactic Fermentation and Its Bearings on Pathology. Trans. Path. Soc. London **29**: 425–467.

(Dilution methods for obtaining pure cultures, see p. 445.)

KOCH, ROBT. Zur Untersuchung von pathogenen Organismen. Mittheil a.d. Kais. Gesundheitsamte (Berlin) **1**: 1–48. *pls. 1–14.* 1881.

(Poured plate and streak method first described.)

PETRI, R. J. Eine Kleine Modification des Kochschen Plattenverfahrens. Centrbl. f. Bakt. **1**: 279–280. 1887.

(Description of the now common Petri dish.)

Rapid development in isolation technique. The most fruitful principles involved in bacteriological culture methods were the outcome of work throughout not much more than a dozen years, practically between 1873 and 1885. On the other hand, the biological facts encouraging and inspiring investigation in this field

had long been accumulating. More than a century prior to the dates mentioned, Bonnet and Spallanzani showed some appreciation of the principles of sterilization and they were more or less successful in attempting to demonstrate that when the organisms in any given nutrient medium are killed, an entrance of germs from without is necessary in order that growth may subsequently occur. Nevertheless, belief in the infelicitous idea of spontaneous generation gained strength, and was not finally abandoned by some prominent scientific men until after the great conquests made by Pasteur and others in the fields of fermentation and disease. An important era was marked by Cohn's demonstration that the spores of many bacteria are particularly resistant to heat, and that it is only after passing into the vegetative condition that boiling may effectually kill such organisms. This led promptly to the adoption of a discontinuous method of sterilization, and thus it became a matter of easy manipulation to grow organisms in media rendered absolutely sterile.

It was in 1873 that Klebs described a "fractional" method of isolating bacteria, and Lister five years later developed a "dilution" method. Viewed in the light of to-day these methods were burdensome, yet they were not impossible in the hands of careful workers. The methods adopted were necessarily extremely crude in comparison with those employed to-day. The dilution process was the surest practical method of isolating yeasts and bacteria. This method consisted essentially in diluting to such extent, in the beaker or other vessel of sterile water, a drop of any fluid containing the organism so that a drop of the diluted material would contain, perhaps, not more than a single cell or organism. This dilution was, of course, based upon a tedious count made under the microscope. If, then, drops of this water in which the organisms or cells were suspended should be transferred one to each of several tubes containing any desired medium, a separation might be effected. Drops of the liquid containing the organisms might also be spread on the surface of a sterile slice of potato, and, with growth, separate colonies might appear. This was practically the status of methods which had been developed for the isolation of microscopic organisms, up to about 1881, which date marks the beginning of a very distinct advance.

Isolation by means of solid media. Credit for the sudden perfection of isolation methods is due to Robert Koch. He had watched to good advantage the difficulties in the way of securing isolated colonies of bacteria on potatoes, or by the older methods, and in search of a more desirable medium, he began experiments in a wholly new field. The outcome of his researches was the substitution for potatoes of a substance which would have both liquid and solid properties. This substance he found first in gelatin and later in agar agar. Either of these could be employed in his simple and efficient poured-plate isolation method. The results of those studies have given us a powerful equipment for the study of the fungi as well as the bacteria. The substitution of Petri dishes for plates, and many refinements in the way of sterilization apparatus followed promptly.

Mycological advances. Meanwhile valuable contributions had been made by De Bary, Brefeld, and others, serving to stimulate research along purely mycological lines. The employment of synthesized media, improvements in the general methods of making nutrient media, and the use of diverse plant products have brought into the work, on the one hand, the development of definite standards, and, on the other, the possibility of cultivating forms once prevailingly thought to be specialized parasites. The recent development and application of culture methods from the phytopathological standpoint has been such as greatly to stimulate renewed interest in systematic mycology, and the physiological aspect of the work has been notably advanced. In fact, the physiological studies of the past ten years have been to a very commendable degree studies in the physiology of the fungi. The simplicity of form, the great variety in species and in habitats, the readiness of growth in pure culture, and the rapid response to stimuli all unite to make these plants favorable material for investigation and demonstration.

II. CLEANING GLASSWARE

Even for ordinary purposes in culture work glassware should be thoroughly cleaned. Any reagents which will conveniently accomplish the purpose may be used, but the general methods followed in bacteriological laboratories are to be advised. Special methods will be necessary in certain cases and here one's knowledge of

chemistry must direct. Ordinarily it is not enough to depend upon hot water and soap in cleaning glass vessels. Petri dishes, test tubes, etc., may be boiled for a short time prior to cleaning, and if grease is present, a small quantity of potash lye (about 30 grams per liter) may be added. If the glassware is immersed in water, a porcelain-lined vessel should be used, and the latter may be placed over the flame or in the steam sterilizer. Commercial hydrochloric acid is convenient in many cases for general use. A chromic acid

FIG. 2. SOME CHIEF TYPES OF GLASSWARE REQUIRED IN STUDENT CULTURE WORK. (Photograph by Geo. M. Reed)

cleaning mixture has also become quite generally adopted and gives excellent results. This mixture may be made sufficiently strong for ordinary purposes by dissolving 100 grams of potassium dichromate in 1000 cc. of hot water, then when the salt is all dissolved and the liquid cool, pour into it about 500 cc. of strong sulfuric acid, stirring constantly. This liquid should be stored in large-mouthed, glass-stoppered bottles, and used with care. It may be used repeatedly. When employed, it may act for from ten minutes to twenty-four hours, and it may be followed by water, or soap and water, etc. This mixture is not convenient to handle but is very effective.

Test tubes. Ordinarily these should be cleaned with hot water, soap and a test tube brush; and this cleaning may be preceded or

followed by the potash solution or the cleaning mixture, as occasion may demand. In either case the tubes are thoroughly rinsed ultimately with distilled water, the outside of each wiped dry, and they are then placed upon a test tube rack. In order that they may dry rapidly and without blemish, they may be rinsed with 95 per cent alcohol. A considerable quantity of alcohol may be used in the first tube, the top of which when shaken is closed with the finger. The same alcohol may thus be used for twenty or more tubes successively. Tubes containing agar, or old cultures, are more easily cleaned after being boiled for some time in the steam sterilizer or in the autoclave.

Petri dishes. These are generally cleaned with hot water and soap. They should be thoroughly rinsed in clean, hot water and wiped while yet hot. It is seldom necessary to leave cultures, or the agar employed in cultures, in these dishes until the medium becomes hard and dry. If so, it may be essential to soak or steam the dishes a long time before cleaning.

Flasks. It is difficult to get at the interior of flasks with any type of brush, whereas reagents are readily employed in cleaning such apparatus. The chromic acid mixture should then be employed, and afterwards the flasks are rinsed and treated with alcohol as for test tubes. If the flasks are desired for immediate use, after the alcohol treatment, they should be rinsed with a small quantity of ether, and may then be rapidly dried with a blast or foot bellows, if one is convenient.

Slides and cover glasses. When new, or when stained, these may be effectively cleaned by the chromic acid mixture, in which they should remain from twelve to twenty-four hours. They are next rinsed, and the slides wiped directly, while the covers should be wiped with cheese cloth or linen after a transfer to alcohol. When the slides are soiled with paraffin, wax, vaseline, or other oily material, boiling in the potash solution or in carbonate of soda will be necessary. The same treatment should be used for tubes sealed with paraffin. Balsam preparations are cleaned by soaking for some time in 75–90 per cent alcohol, and then by rinsing in waste xylol, benzine, or other such solvent of the balsam.

Special methods. For studies in nutrition, germination experiments with special stimuli, and other very careful physiological

work, it is necessary to have glassware which is not only clean with relation to extraneous substances, but which is as far as possible free from the soluble substances which may be contained in the glass itself. In the first place, it is well to have vessels of Jena or of the best Bohemian glass. Such glassware may be first cleaned by the ordinary process. This is followed by boiling in the potash or other alkaline solution. The vessels are then rinsed and boiled in weak hydrochloric acid, and rinsed again. Finally, they are filled with distilled water and steamed for a number of hours.

In this connection it may be said that cover glasses which have been perfectly cleaned and dried will give more trouble in the preparation of hanging drop cultures than those less perfectly washed. On the former there is a tendency for the drop to spread or to shift its position at the slightest movement. Loss of stability in the drop should, however, be sacrificed to absolute cleanliness if one is doing quantitative work. The drop will have even a greater tendency to spread if the cover glasses are flamed immediately before being used. To avoid this latter difficulty, if wiped with a clean sterilized linen cloth and placed in a sterile Petri dish just as they are taken from the alcohol, there will be practically no danger of contamination.

Cover glasses which are to be used in making preparations of bacteria should be absolutely clean, and the method above mentioned, namely, boiling in an alkali, in acid, and in distilled water is requisite. They should be air-dried from strong alcohol. Thus prepared, the covers will permit the operator to spread uniformly over the surface a drop containing bacteria.

III. THE PRINCIPLES AND METHODS OF STERILIZATION

Vessels and media. Sterilization, as the term is generally employed, is merely the process of killing all of the organisms or spores which may be present in a medium or vessel or upon a given object. In culture work sterilization, therefore, is more particularly employed when a substance or vessel is to be used for the culture of a particular organism, or to preserve nutrient media from decomposition. The common and most effective method of sterilization is by means of heat. Some important uses of chemical agents in sterilizing are not here considered. Steam heat or

dry heat may be used, depending upon the nature of the medium or object to be sterilized. Liquids or any solids which may melt, evaporate, or dry out in a dry atmosphere require moist or steam heat; while all heat-resistant dry apparatus and glassware, and well-dried solids, such as sand, glass wool, etc., usually require dry heat.

Sterilization at 100° C. When steam heat is used, sterilization is often given at the boiling point of water. Sterilization may thus

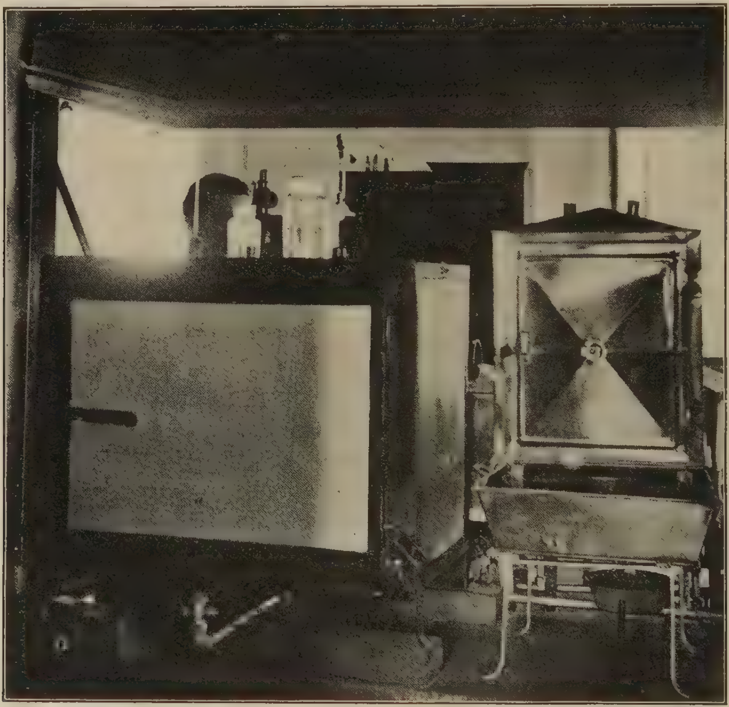


FIG. 3. ON THE RIGHT, ARNOLD STEAM STERILIZER; ON THE LEFT, LAUTENSCHLÄGER HOT AIR STERILIZER; BOTH UNDER HOOD

be effected in an ordinary boiler, or over a water bath. Steam sterilizers of various patterns are now made, which accomplish this work most effectively, and they should be in use in all laboratories. The two general types of sterilizers in common use are those which bear the name of Koch and Arnold. The latter are simpler in design and less expensive. Fig. 3 shows a good form of this sterilizer. From the diagram, Fig. 4, it will be seen that the water

in the chambered bottom is rapidly brought to the boiling point, and then the gradual entrance through the holes of water from the reservoir will supply the boiler for several hours, if it is necessary to employ it so long.

The Koch sterilizer is now less used. Aside from being a well-made piece of apparatus, it has only the advantage that the regulation of the water supply is automatic. It is expensive and is only especially desirable in case of sterilization or digestion for many hours.

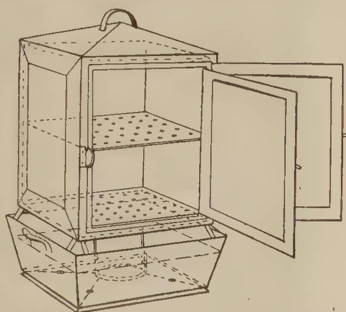


Fig. 4. Arnold Steam Sterilizer, Square Type, showing Construction

Countless experiments have shown that while the vegetative cells of most bacteria are usually killed by a single sterilization of from fifteen minutes to one hour at 100° C., yet the spores of many forms are not killed by one exposure at this temperature. As a matter of fact, an exposure for a few minutes at 100° C. in the steam sterilizer is usually sufficient to kill the growing parts of most fungi. It is not, however, such delicate parts which are to be reckoned with in the sterilization of nutrient media, but rather the resistant spores of fungi and bacteria, and thick-walled mycelial parts. Forms which are strongly heat-resistant may often be encountered in the preparation of such media as potatoes and manure decoction.

To Cohn is due the notable discovery of heat-resistance in the spores of bacteria, and logically following this Tyndall demonstrated the necessity of discontinuous or successive sterilization, after intervals sufficiently long to permit such organisms, or parts of organisms, as have remained as spores to germinate, and therefore to be more readily killed at the next heating. In general, it is necessary to sterilize on three successive days. As is well known, when one is careful in making the medium a single sterilization of half an hour is usually sufficient for tubes of agar, if the apparatus has not become infested with particularly resistant spores. In no case, however, should one depend upon a single sterilization unless the material is to be kept several days previous to inoculation. Stock

quantities of media should be sterilized three times. Between the periods of sterilization media should be placed at a temperature favorable for most bacterial development, and not in a cold place, this being in order that any spores might pass into the vegetative

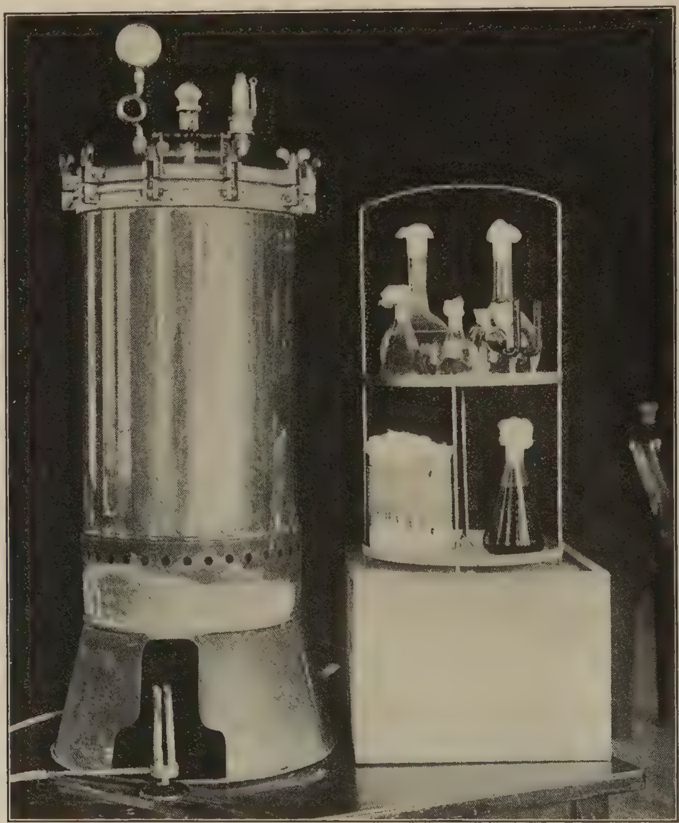


FIG. 5*a*. AUTOCLAVE, ERECT TYPE, CLAMPED TOP, HEATED BY GAS
(Photograph by Geo. M. Reed)

state within twenty-four hours, and thus be killed at the next sterilization.

A suggestion which has been made by Theobald Smith is of interest in connection with the sterilization of media which may contain anaërobic bacteria. If such media are sterilized in thin layers, oxygen may have comparatively free access to any submerged

spores, and consequently they may not germinate between the successive sterilizations. On the other hand, if the medium is deep in the vessel, and the exposed surface of the medium small, much less oxygen gains access, and the spores of anaërobic forms pass more readily into the vegetative condition and are killed by the successive sterilizations.

Sterilization under pressure. A great time-saving convenience in sterilization is to be found in the use of the autoclave, or steam

FIG. 5*b*. AUTOCLAVE, HORIZONTAL TYPE, CONNECTED WITH STEAM PIPES
(All steam apparatus under a hood)

pressure sterilizer, two types of which are shown in Fig. 5, *a* and *b*. The autoclave is not only more effective than the ordinary steam sterilizer, but by using it the delay of discontinuous sterilization is avoided. In this apparatus the steam is confined, up to any pressure desired, instead of being allowed to escape, as in the ordinary steam sterilizer. A good steam pressure gauge on the autoclave is requisite, and a thermometer is not only desirable, but also an additional safeguard. The temperature ordinarily employed is 115° to 125° C., or about 10 to 20 lbs. pressure. A single incubation

of from fifteen to twenty minutes at this temperature will usually sterilize any medium. The period of incubation must of course be measured from the time the desired temperature is attained, and it may require from ten to fifteen minutes, even with a strong burner system, in order to reach this temperature. An autoclave containing an ordinary amount of culture vessels should, if provided with a double ring of burners, and jacket, develop a pressure of 15 lbs. in about ten minutes.

Temperatures higher than 115° may transform, possibly through acidity, many sugar-containing and other organic media, and consequently greatly reducing their value for the growth of many organisms. Gelatin and milk are injured, if acid, by autoclave temperatures. With more readily decomposable substances sometimes necessarily employed in phytopathological work, it may be possible to effect sterilization at temperatures below the boiling point, at from 80° to 90° C., say, sterilization being made on about six successive days. The blood serum incubator may also be employed.

Not only does the autoclave facilitate sterilization, but it is economical in the preparation of media to such an extent that it should be in general use. The expense of such a piece of apparatus is the one factor operating against its general adoption, yet a good instrument handled carefully should last a number of years.

The autoclave may be heated by burners, or it may be connected with a steam supply pipe, if a supply of steam under sufficient pressure may be constantly at hand. Autoclaves are usually prepared for gas burners. In using this instrument care should be taken to arrange mechanical reminders if there is danger of its being neglected even for half an hour. It might be suggested that an alarm clock as such is useful, or that a clock arrangement for shutting off the gas at the desired time is in use in some laboratories. With the gas-heated autoclaves, particularly, certain precautions are necessary. Before each sterilization it must be noted that sufficient water is present, usually up to the crate or false bottom; and it is well to employ distilled water. The lid and other fittings should be kept free of dirt and dust, so that all fastenings may be tight and secure. If the burner capacity is not too great, the gauge screw may with little practice be set at the temperature desired, the steam vent left open, and the apparatus lighted. A few minutes after

steam begins to escape vigorously, or practically as soon as the thermometer registers 100° C., the vent is closed. It is not advisable to leave the autoclave without observation during sterilization, since there are many chances for mishaps; nevertheless, if the safety valve is set for a given pressure, steam will, of course, be blown off at about the temperature desired. This blowing off of steam is a good signal for cutting off a part of the gas supply, as the rapid escape of steam not only results in exhaustion of the small reservoir, but often dislocates the cotton plugs. When the time for sterilization has elapsed, the gas is turned off; but the steam vent should be only gradually opened as the pressure falls to 100° C., else the medium may boil over and the plugs will be blown out of the vessels. If steam is used instead of a gas burner, a complicated set of stop-cocks will be required, or will at least be advantageous, to regulate the inlet and exit of the steam.

Hot air sterilization. Implements, glassware, cotton, sand, and other vessels or materials used in culture work, which may not be sterilized by steam or by the burner flame direct, are sterilized in a hot air sterilizer. It is true that the delicate mycelium and spores of many fungi are often injured or killed by drying alone; yet, on the other hand, the spores and mycelium of many fungi are extremely resistant to desiccation and to a high degree of dry heat. By long practice it has been ascertained that it is not safe to attempt to sterilize vessels in a dry oven at less than 150° C. for one hour, or at a slightly lower temperature with protracted sterilization. Test tubes or flasks plugged with cotton, or Petri dishes wrapped with paper, cannot well be exposed to a much higher temperature. Glassware may safely be exposed to a temperature of 170° C., or higher. The best form of hot air sterilizer is the Lautenschläger, Fig. 3, yet a simple and inexpensive oven will suffice.

Sterilization of soil. In all inoculation work where there is danger of contamination from the soil, and particularly in the study of root and stem diseases, experiments with damping-off fungi, and the like, it is necessary to use sterile soil and sterile pots. The pots may be prepared with soil as for the growing of any plants, well watered, and then sterilized a few at a time in any steam sterilizer or autoclave. In the former they should be sterilized at least two or three hours after the temperature has reached 100° C., and

this should be repeated if possible the next day. This method is available when there is only a small number of pots to be handled. When, however, the work must be conducted on a larger scale an effective apparatus is the Britton soil sterilizer. Britton has described[1] a steam sterilizer for soils which he has devised for use in the station greenhouses. This apparatus is simple and seems to be wholly practicable. It is described as follows:

It consists of a square box made of heavy galvanized sheet-iron connected with the steam-heating system in the potting room of the forcing-house (or elsewhere convenient). This box is cubical in form, each of its three dimensions being thirty inches; six inches of the top is in the shape of a removable cover. Steam enters through a hole in the center of one side, to which side is soldered a coupling. A three-fourths inch pipe, fitted with a valve, connects the apparatus with the steam-heating system. A few strips of wood placed under the box raise it a half inch from the cement floor to prevent rusting. Inside the metal box are similar strips upon which the trays rest. Two small holes in the bottom allow the condensed water to escape.

The soil is placed in the trays which are made of wooden frames having bottoms of galvanized wire netting. The frames are made of strips of wood three and one-half inches wide and seven-eighths of an inch thick; after fastening the netting, a half-inch strip is nailed on to hold the netting firmly and to cover its jagged edges. The dimensions of the trays in inches are $27 \times 13 \times 4$ over all, and inside are $25\frac{1}{2} \times 11\frac{1}{4} \times 3\frac{1}{2}$ inches.

The wire netting has six meshes to the inch. Soil is spread loosely and evenly in the trays to the depth of about three inches and the trays packed inside the metal box in cob-house fashion. . . .

There is a space of one and one-half inches all around the trays inside the box, and a space of an inch between the two trays. The half-inch strips on the bottom edges of the trays allow the steam to enter above and below the coil in each of the trays. As the steam comes in contact with the soil, both above and below it, much less time is required to heat it than when in a solid mass. The sterilizer contains fourteen trays, which, when filled to the depth of three inches, hold 6.9 cubic feet of soil. . . . Steam entering through a three-fourths inch pipe at a pressure of five pounds per square inch, heats the soil to the boiling point of water in about fifty minutes — a great deal depending, of course, on the density of the soil, as a loose soil heats through much more rapidly than if packed closely. The box is not steam tight, but nearly so for a low pressure; considerable expense would be necessary to make it perfectly steam tight and at the same time permit of convenience in opening the box.

Soil was kept in the apparatus one hour for the purpose of killing the nematodes. This also doubtless destroyed many fungous germs, but where absolute

[1] Britton W. E. A Steam Sterilizer for Soils. Conn. (New Haven) Agl. Exp. Sta. Report (1897): 310–312.

sterility from bacteria and fungi is desired it would be necessary to steam the soil for a much longer time. The steamed soil is also almost wholly free from live seeds of weeds while the untreated soil was considerably infested with various common weeds.

A sterilizer may be arranged more or less after this pattern, but with particular reference to the conditions at hand. A sterilizer of this type may also be used for pots and saucers already filled with soil. A better pressure of steam may be secured, of course, if the sterilizer is directly connected with the boiler. For summer work, moreover, it is not desirable to have the sterilizer connected with the general heating system.

Soil sterilized by dry heat requires a very high temperature, and is unquestionably somewhat injured in the process. On the other hand, it must be remembered that soil which has been steam-sterilized encourages upon reinfection the growth of such saprophytic organisms as Mucor and Penicillium, and possibly such hemisaprophytes as Rhizoctonia and other fungi causing root diseases. Care must be taken, therefore, not to permit these organisms to get a start in the soil before normal bacterial action has begun.

IV. PREPARATION OF CULTURE MEDIA

Liquid Media

Except in investigations where a medium of known composition is required, or in drop cultures and the like, liquid media are less used for cultural purposes with the fungi than with the bacteria. In many physiological studies, however, such media are desirable or indispensable, and as a rule these liquid media form the nutrient bases for the making of most of the gelatinous solid media employed in mycological work.

Plant decoctions are undoubtedly of the first value for work with the fungi, and with these organisms they may entirely replace bouillon, considered so essential in the culture of bacteria. Some of the most nutritious and convenient plant decoctions may be made from the sugar beet, white potato, carrot, pods and stems of bean, or vetch, prunes, apples, celery, and various other plants or plant products. In order to secure more or less uniformity in the composition of these decoctions, for every 1000 cc. of water used it

has been my practice to require 50 grams dry weight of the plant product. Accordingly, from a mean of several analyses brought together, it would require about 490 grams of beet root, 400 grams of bean stems or of string beans, 120 grams of dried prunes, and about 390 grams of the fresh potato.

The plant product is washed, and, if desirable, pared, cut up finely, or thinly sliced, and then the necessary water is added. It is next boiled in the steam sterilizer for about two hours, or in the autoclave at 115° C. for twenty minutes. If necessary to boil over a steam bath, a flask plugged loosely with cotton, or a small-mouthed agate pitcher covered with flannel, should contain the material, so that a minimum of evaporation will occur. The clear liquid is filtered off through several thicknesses of filter paper into a sterile flask, when it may be immediately used in making solid media, or sterilized as usual for preservation. Where it is particularly desired to obtain the clearest decoction possible, the liquid may be cooled to about 60° C. under the tap, or by pouring from one vessel to another, and then the white of an egg may be added. The decoction is again boiled for an hour in the sterilizer, or about fifteen minutes in the autoclave; and the clear liquid finally filtered away from the coagulated albumen and sediment.

It will often be necessary, or well, to make decoctions of various other plants, particularly of fleshy fungi, of the host plants upon which certain fungi grow, etc. Such decoctions may be particularly desirable in physiological work.

Manure decoctions of any kind are particularly serviceable in the study of many saprophytic organisms, but in pathological work these liquids are no more valuable than any of the plant decoctions. Special emphasis might be laid upon prune juice, or prune decoction, especially when the fungus is one which may inhabit saccharine fruits, berries, etc.

It will be readily suggested to the student that plant products of various kinds may be roughly grouped into such as are rich in albumens, starches, sugars, etc., and these products will be selected and employed in accordance with such indications with respect to the needs of the fungus as are available.

Bouillon, the chief fluid medium used for the bacteria, is an extract of beef, practically a beef tea, to which peptone is added.

It is usually made directly from lean beef, and is an infusion of the beef in twice its weight of water. To prepare it, 500 grams of lean meat, as free as possible from fat, are chopped or ground finely, and to this is added 1000 cc. of distilled water. It is then placed in a cool place for twelve to fifteen hours, and occasionally stirred, if possible; or it may be placed in a water bath at 65° C. and frequently stirred for a period of about one hour. By the latter method the bouillon is said to contain some less desirable substances, but it will often be found the more desirable process for students who cannot be at the laboratory regularly. All of the juice possible should be squeezed out of the meat, and a hand press is frequently used by bacteriologists to accomplish this more effectively. The red liquor filtered off through cheese cloth is made up to one liter with water, and then to it is added 10 grams of peptone and 5 grams of sodium chloride. It is then heated in the steam sterilizer for one hour, or in the autoclave fifteen minutes, when a clear liquid with a well-differentiated coagulum is to be seen. This is filtered readily through filter paper. The bouillon will now be slightly acid and should be neutralized or given the desired reaction with sodium hydrate (see page 33). For ordinary purposes with fungi it may be enough to use the litmus paper test, but special methods of neutralization are essential in the most careful work either with fungi or bacteria. These must be adhered to for accurate physiological work, or for furnishing descriptions of the fungus on specified media. If the bouillon is not perfectly clear, an egg also may be used as with the plant decoctions, to effect clarification. The medium is next sterilized and preserved. Prepared meat extracts are used by some in making bouillon.

Milk and litmus milk are only important with the bacteria. Fresh milk alone should be employed, and from this the cream should be removed either by the centrifuge or by standing. Litmus milk is made by the addition of 2 cc. of a saturated solution of blue litmus to each 100 cc. of milk. This is extremely sensitive to the development of alkalis or acids during the growth of organisms.

Synthetic liquid media, as they are termed, that is, media prepared by the use of salts, carbohydrates and other substances of known composition are more extensively used in physiological work. There the specific purpose of the experiment should be depended

upon to determine the composition. These media are, however, important in all culture work. The following solution has been in such common use as to be generally designated a standard nutrient solution:

Ammonium nitrate	1.0 gram
Dihydrogen potassium phosphate	.5 gram
Magnesium sulfate	.25 gram
Iron chloride	trace
Cane sugar	5.0 grams
Water	100 cc.

With some fungi the addition of a small quantity of sodium chloride is advantageous.

Among the many other culture fluids which have been used, one of the most important available alike for fungi and bacteria, although not ideally constituted, is Uschinsky's solution, made of:

Ammonium lactate	6–7 grams
Sodium asparaginate	3–4 grams
Potassium hydrogen phosphate	2–2.5 grams
Magnesium sulfate	0.3–0.4 grams
Sodium chloride	5–7 grams
Calcium chloride	0.1 gram
Glycerin	30–40 grams
Distilled water	1000 cc.

Experience in culture work will promptly demonstrate that the concentrations of the above solutions are to be regarded as important because they establish standards. In special cases, however, it may be desirable to increase considerably the amount of carbohydrate, and this, in turn, may render desirable further changes.

Solid Media

Nutrient agar agar. Agar, or agar agar, is a substance somewhat of the nature of gelatin. It is, in fact, a kind of gelatin, or glutinous substance, made from certain seaweeds, especially species of *Gelidium* (Fig. 6) or *Gloiopeltis*, which grow abundantly on the coasts of Japan and China. The commercial article is usually obtained in the form of shred-like strips, or as a powder. Agar has this advantage over gelatin, namely, that at a suitable strength it will remain solid up to a temperature of at least 95° C., and it

very seldom becomes liquefied by the action of growing organisms. Nutrient agar agar consists of some nutrient "base," like sugar beet or prune decoction, bouillon, etc., to which is added, for purposes of solidification, 11 to 15 grams of the commercial agar agar per liter. The nutrient base, whether plant decoction or bouillon, may be made as already indicated. There are then several methods of procedure for making the agar. (1) When an autoclave is at hand, 12 grams of the agar are merely cut up finely into a liter of the desired decoction and this is placed in the autoclave and steamed at from 110° to 115° C. In thirty minutes the agar will be

FIG. 6. *GELIDIUM CORNEUM* LAM., FURNISHING AGAR AGAR
(After Erw. F. Smith)

dissolved. It is then neutralized, or brought to the desired reaction; and if not clear, the white of an egg may be added, as usual, when a second similar or shorter steaming is necessary. (2) This same method may be used with the steam sterilizer, except that it may require from one to two hours for the complete solution of the agar. Some grades of agar dissolve very slowly by this method, and it is often recommended in such a case to soak the agar previously twelve to eighteen hours in water containing sodium chloride. (3) Many find it more convenient to put the agar into an agate iron cup, add about 200 cc. of distilled water and boil directly over a flame, stirring constantly, until the agar is thoroughly dissolved. This is then added to the decoction to be used. This last

method requires more of the personal attention of the operator, but it insures successful solution of the agar. The medium may be then cleared in the usual manner.

In making nutrient agar, a chief difficulty for the beginner has been with relation to filtration, which is necessary in order that a clear product may be obtained in which the development of micro-colonies may be carefully followed. If the agar is thoroughly dissolved, it filters with comparative ease; whereas, if partly dissolved, filtration is next to impossible. In any case a grooved or ridged filter, good filter paper wet with hot water immediately before using, and well-dissolved agar direct from the pan, steamer, or autoclave are the requirements. Nevertheless, in case of difficulty, the filter stand with funnel and flask may be placed in the sterilizer or autoclave to be kept thoroughly hot during the process. Again, a side-neck filter flask may be used so that connection with a filter pump attached to the tap may be secured. In the latter case porcelain supports and cotton may be substituted for filter paper.

After filtration the agar may be poured into flasks or test tubes (usually about 8 cc. per tube, when used for isolation cultures), subsequently sterilized and stored.

A synthetic liquid medium may be used as a nutrient base with agar. The standard salt solution previously mentioned and many others are serviceable; however, since agar is a medium the composition of which is complex, it is often too "impure" as to known qualities for certain physiological studies. Long washing is of value, but this may not remove all materials furnishing food substances. A few drops of hydrochloric acid in the water will also materially improve the purity of the agar, but it may injure or entirely destroy the solidifying properties. In most instances it is best to substitute for the agar Winogradsky's silicate jelly, or resort to cultures on tightly folded bars of filter paper or some other pure substance. Glycerin agar is particularly serviceable in culturing slow-growing fungi. It is made by the addition of 5 per cent glycerin to the prepared medium.

A stiff agar, made by using from twenty to thirty grams of agar for each liter of solution, is desirable when cultures are to be transported. It is also valuable, employed in large flask cultures, in order to obtain the fruiting stages of many fungi.

Nutrient gelatin is employed extensively in the cultivation of bacteria, but seldom with the fungi. It is made by adding 100 grams of gelatin to each 1000 cc. of bouillon. In the preparation of this medium one must use as little heat as possible. It dissolves readily in hot bouillon, and filters much more quickly than agar. The congealing properties of gelatin are destroyed by a long exposure to a greater temperature than 100° C., so that if the autoclave is employed, then the gelatin should be cooled promptly. When sterilized, the periods of steaming should not exceed ten or fifteen minutes. Gelatin melts at a temperature above 35° C. and often lower, so that it must be stored in a cool place; and the cold water box of Novy (Fig. 7) may be used to afford such a low temperature when the refrigerator is unsatisfactory.

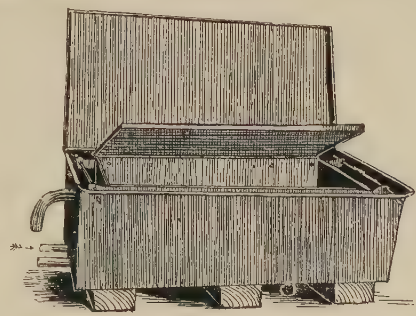


Fig. 7. Double-Walled Metal Box for Storage of Gelatin Cultures; connected with Water Supply. (After Novy)

Starch jelly should become an important nutrient medium. It can be obtained fairly pure, and in connection with synthetic salt solutions it is valuable for slanting tubes. Commercial starches generally contain resistant spore-forming organisms, and it is desirable to shake up the starch in a flask with 95 per cent alcohol for one hour and dry rapidly on filter paper before using. A 10 per cent mixture in the salt solution selected should be made. Rub this up well before heating, and sterilize, if possible at from 90° to 93° C. on successive days.

Vegetable products. Cylinders or slices of vegetables, such as the sugar beet or potato, or even young stems or pods of bean, prunes, squash, corn meal, etc., prove excellent media of different types, most suitable for work with the fungi. The sugar beet is an excellent general medium, rich in cane sugar. It is quite generally obtainable during the autumn, and laboratories may then be provided with a supply which will keep in a cellar over winter. The potato is always available and offers an excellent starchy medium. The stems or young pods of bean are rich in nitrogenous material,

but in the preparation of these more care is necessary for the prevention of bacterial contamination. This is one of the most nutritious culture media known for fungi in general. String beans may be obtained on the market at almost any season. Celery leaf stalks are a medium rich in nitrates and desirable for some organisms. All of these highly nutritious media are excellent for securing the vegetative growth of an organism, but it is very often the case that with such media fruiting stages are not obtainable. I have almost invariably obtained better fruiting stages by using ordinary corn meal, or maize meal. This can be prepared to advantage in small flasks. The flask is filled with meal to a depth of about two thirds of an inch. This is then wet with water, hot water being preferable, as cold water does not wet it so readily; and enough water is added to make the meal quite soft, since considerable water will be absorbed during sterilization. Cylinders or plugs of various root crops, or stems of plants, dead wood, and various other products, may serve special purposes.

In preparing the cylinders of root crops, the roots should be thoroughly washed and pared, and then cut into pieces of desired size. If used in a test tube, a scoop which cuts out a cylindrical piece will be found convenient. These cylindrical plugs, say three inches long, are then cut diagonally. Ordinarily a piece is placed in a test tube of $12-15 \times 150-180$ mm., and then ½ to 1 inch of water is added. More desirable for many purposes, and particularly for transportation, is to put in each tube half an inch or so of saturated absorbent cotton, and within this rests the end of the nutrient substance, which is thus firmly held in place. The latter method avoids all fluids in the cultures, and the tubes may be inclined or placed upright afterwards, as convenient. In somewhat the same way wads of absorbent cotton or of filter paper may be placed in the tubes, and these wads then moistened or wet with any nutrient solutions desired, and subsequently sterilized. Closely folded pieces of filter paper may be used in this way with solutions of known composition for very accurate work in nutrition; and in such cases a supply of the liquid may also be placed in the tube so that the culture may not dry out for a considerable period.

It is often desirable, and indispensable for the best growth, to use in connection with a culture liquid of known composition some

solid substratum, serving principally, perhaps, as a means of aëration. Wads of pure filter paper, or elder pith which has been carefully purified, are both serviceable.

Certain parasitic, fleshy, or bracket fungi may be grown to advantage upon dead or normal wood. With a proper regulation of the moisture content of the culture chamber fruiting is often readily induced upon such media when other substrata fail.

Silicate jelly. Silicate jelly as a substitute for gelatin and agar was introduced primarily to overcome the difficulties experienced in isolating certain organisms in the cultivation of which it is desirable to avoid organic media. There is, however, a much wider use for this preparation. As finer methods are developed it becomes more and more desirable to employ synthesized media for a variety of purposes. At best gelatin and agar are of uncertain composition, and when, for example, one wishes to determine accurately the value of nutrient substances for an organism requiring solid media, silicate jelly is most serviceable. This material is not difficult to prepare when precautions are taken, and the writer has found it practicable in connection with any mineral or organic nutrients tested.

The following materials and special apparatus will be required for 500 cc. of the silicate jelly.

a. 1 Baumé hydrometer for liquids heavier than water.

b. 200 cc. HCl (sp. g. 1.10° Baumé).

c. 200 cc. sodium silicate (sp. g. 1.09°).

d. collodion sacks for dialyzing.

e. 100 cc. nutrient salt solution five times desired strength.

Stock solutions of *b* and *c* may be kept on hand, also of *e*, if the same nutrients are to be employed in many experiments. Strong hydrochloric acid is diluted with pure distilled water to test 1.10° Baumé at 15° C.

Sodium silicate, water glass, is obtainable at a specific gravity of about 1.38 to 1.42. Distilled water may be added to this slowly until the hydrometer registers 1.09° B. It will usually require about seven or eight times as much distilled water as silicate to give the specific gravity desired. When required the standardized silicate is then added cautiously (dropping rapidly) to the acid, constantly stirring.

Collodion for the dialyzing sacks is prepared by dissolving five grams of guncotton in 100 cc. of a solvent consisting of equal parts of absolute alcohol and sulfuric ether. The sacks are preferably prepared by the test tube method, and convenient tubes will measure about 30 by 200 mm., with lip. The tubes must be thoroughly cleaned (a final rinsing with ether being desirable) and dried. The tube is held in a slanting position and gradually revolved as about 50 cc. of the collodion is slowly poured in, and thus an even roll, or coating throughout, with no bubbles, should be effected. A second coating is obtained by similarly revolving the tube as the surplus collodion is poured out. The tubes are then supported upright, mouth downward, and the drip at the lip removed. They should then be dried rapidly in a draft at a window or preferably under an electric fan, or by exhaust, constantly revolving each tube meanwhile to maintain even distribution of the collodion. When dry, first free the edge of the collodion from the tube with a scalpel and then immerse the tube in a vessel of water so that as the sack is made free water will pass in between the collodion film and the glass, and thus the removal of the film may be readily effected.

The silicate mixture is put in these tubes and they are tied securely with a rubber cord and suspended in water over night. Running tap water may be commonly employed, but for more accurate work it will be necessary to use changes of distilled water. The dialyzed liquid should react neutral to litmus and should show only a trace of chlorides with silver nitrate.

The nutrient solution employed may be that mentioned on page 26, except that the concentration is five times as strong, as previously indicated. It is now necessary to boil both the silicate preparation and the nutrient solution a few minutes to remove air. Then cool down to room temperature, mix and stir, and put into the separatory funnel to facilitate pipetting into tubes or other vessels to be employed in the work. The silicate in the desired vessels is then autoclaved for about fifteen minutes. This should insure thorough solidification. Slanting tubes may also be prepared. It may be necessary for the operator to vary the concentration of the salts, or to experiment with small quantities when using unusual proportions of mineral salts.

Neutralization of Culture Media

Neutralization, or properly titration, of most culture media is required. It is required in order that definite standards may be maintained. In fact, titration is superfluous only in rough work. In general, the degree of alkalinity or acidity of the medium may affect some of the characteristics of organisms, and, therefore, a description of any organism should be made either at a fixed standard of alkalinity or acidity, or it should at least be possible to reproduce exactly the reaction of the medium employed. The colonies of *Bacillus prodigiosus* and other pigment-forming bacteria are less brilliantly colored when the media are distinctly acid. To slight differences of reaction in the substratum fungi ordinarily show no marked cultural variations; yet to greater differences they may respond by variations in color, modifications of colony form, amount or character of fruiting, etc.

Most culture media are acid, and sodium carbonate was formerly employed in neutralization. From this, however, carbonic acid is liberated, and litmus is temporarily reddened, so that potassium hydrate or sodium hydrate is preferable. Moreover, in this titration work phenolphthalein, a reliable indicator, has been adopted. It is more desirable than litmus, rosolic acid, or other indicators. Litmus may be used for rough work, but it is less sensitive to certain acids and too variable. In peptone, gelatin, and other organic substances there are bodies which are amphoteric, that is, which possess both basic and acid properties, the latter predominating. Phenolphthalein is particularly serviceable with respect to those substances. Litmus fails to detect such weak acids; again, litmus reacts alkaline to the dibasic phosphates, while phenolphthalein reacts neutral.

In titration, the following solutions are desirable: $\frac{1}{2}$ per cent phenolphthalein in 50 per cent alcohol, as indicator; $\frac{1}{20}$ normal caustic alkali (preferably sodium hydrate) for the titration; and a normal solution of the caustic alkali for actual neutralization of the medium.[1]

[1] For practical purposes, a normal solution of sodium hydrate may be prepared by dissolving 4.5 grams of c.p., fresh NaHO in somewhat less than 100 cc. of distilled water, and after it is dissolved make up with water to exactly 100 cc. (roughly, this amount makes due allowance for the water and impurities in fresh NaHO).

Fuller's procedure modified may then be a guide; this is as follows: (1) Measure by a volumetric pipette or burette 5 cc. of the culture medium, and dilute it with distilled water to 50 cc. (2) Boil for three minutes in a porcelain dish. (3) Add 1 cc. of the stock solution of the indicator, phenolphthalein, and titrate by adding the $\frac{1}{20}$ per cent caustic alkali from a burette. Stir constantly, and a permanent faint pink coloration will indicate the first appearance of alkalinity. Those inexperienced in the work should always take two or even three samples of the culture liquid and compare results as to the amounts of alkali employed. The data are then at hand for neutralization or for making the medium correspond to a desired reaction. If 6 cc. of the $\frac{1}{20}$ normal alkali, for example, is required to bring the two samples to the point of neutralization, then the remaining 990 cc., assuming that we employ a liter of culture medium, would require practically 100 times 6 cc., or 600 cc. of $\frac{1}{20}$ normal, which is equivalent to 30 cc. of normal alkali. Ordinarily, the medium is not neutralized, but is left acid to the extent of an omission of 10–15 cc. of normal alkali per liter. In the example above, therefore, 15 or 20 cc. of normal alkali would be added. A control titration may also be made.

V. PRESENT METHOD OF ISOLATING ORGANISMS

In making cultures with a view of isolating, or separating out various microscopic organisms, the poured-plate (Petri dish) method is now almost exclusively employed. Such cultures may be called isolation or separation cultures, the use of the old term *dilution culture* being less desirable.

Materials needed. In order to make these isolation cultures, one requires nutrient media and apparatus more or less as follows:

Sterilized Petri dishes, of about 100 mm. diameter; test tubes containing about 10 cc. of sterile agar agar; a few very short test tubes without agar; a platinum needle; a beaker, or tumbler, with some cotton in it, to hold the tubes; a thermometer; and some boiling water. The agar in the tubes is melted, either in the steam sterilizer or in an open casserole of boiling water with cloth or cotton at the bottom. In ordinary culture work, as well as in bacteriological work, three tubes, and consequently three Petri dishes, constitute an isolation series. Three tubes of melted agar are

placed in the beaker, which is filled with water at from 40°–42° C.; and this temperature, which is above the point of solidification of agar, should be maintained throughout the period of culture by the addition of hot water when necessary.

The method. In making the cultures the procedure may be as follows: Some of the spores or bits of the material from which cultures are desired are diffused in a drop of sterile water placed in one of the short test tubes (or a flamed slide will suffice). The three tubes in the beaker are denoted 1, 2, and 3 respectively, and may be so marked with a wax pencil. The short tube containing the spores and tube No. 1 are taken between the thumb and index

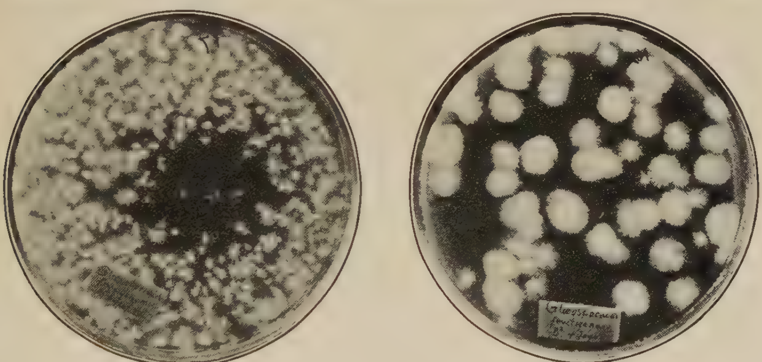


FIG. 8. TWO DISHES FROM AN ISOLATION SERIES OF A PARASITIC FUNGUS (Photograph by Geo. F. Atkinson)

finger and the index and middle fingers respectively, and held almost horizontal, palm upward, the plugs having been previously removed and held between the spaces of the remaining fingers. The flamed but cold platinum needle, provided with a loop at the tip, is taken in the right hand, dipped into the drop of spores, and then into the agar of No. 1 and mixed. This may be repeated several times, unless the spores in the drop are very numerous. No. 1 is now placed in the former position of the short tube, and No. 2 in the place of No. 1. The process is repeated with this combination, and, finally, with Nos. 2 and 3; the contents of each tube is then poured into a corresponding Petri dish upon the top of which number, date, and any description desired may be inscribed with the wax pencil.

Frequently, it will be found in practice that in making cultures of many parasitic fungi so few spores will be available that they may be inserted directly into tube No. 1, and it will be necessary to pour a few drops of the agar from No. 1 to No. 2. In fact, No. 2 will usually give a very good isolation; and then No. 3 may be used as a No. 2, to which is added a drop of 50 per cent lactic acid. Fig. 8 shows an isolation series of *Glomerella rufomaculans*, the bitter rot fungus.

Elimination of bacteria in isolating fungi. The use of lactic acid in culture media is an important aid in eliminating certain troublesome bacteria. In general it may be well to prepare some tubes with lactic acid in about the amount above indicated, practically .5 per cent, so that all tubes used in the isolation series may be thus acidulated without danger of contamination. Acidulated media are especially valuable when separation cultures must be made by using hyphæ from a mixed culture, or from any other source which permits extraneous organisms to come in. In such cases the mycelium should be washed as carefully as possible in distilled water, and then on being placed in the tubes of liquefied agar, the tubes should be vigorously shaken before the contents are poured into the Petri dishes. If, however, there is nothing to indicate the relations of a fungus to acidity, one isolation series should be made with neutral, or very slightly acidulated agar.

Colony counting. In bacteriological work, and sometimes in purely mycological work, it is desirable to make accurate count of the number of spores or cells which may have been present in the material from which the culture is made. Under such circumstances a leveling table must be employed in making the poured plates or Petri dish isolation cultures. Plates of glass or other devices, such as cardboard charts, especially calibrated for counting colonies will also be necessary.

Study of the isolation colony. In the study and transference of the fungi which may appear in isolation cultures, there is a rough method which may be pursued, and there is a careful method which must be followed if one is to be sure that the life history of a particular fungus has been accurately traced. In the first place, one may wait until the colonies have appeared, and perhaps until growth has been considerably advanced. Then, if isolation is

perfect, the species may be more or less readily differentiated, and with a sterile needle transfers may be made of each of the one or more promising sorts to such media as may have been prepared for the purpose. This method suffices, of course, when the desire is merely to get cultures of different fungi. When, however, one wishes to get the product of a certain kind of spore, it is absolutely essential to follow the germination of this spore in the Petri dish, to locate germinating spores at a distance from any other organisms, and then to mark the glass and observe these from day to day or to directly remove these isolated spores with some of the surrounding agar by means of a sterile needle, or scalpel point, to tubes of prepared media. In the latter case a considerable number of such cultures should be made, and the results may not be taken as entirely conclusive unless there is agreement between the cultures thus made. When the fungus is one possessing characters by means of which it may be readily determined, the problem is not difficult.

Frequently the spores which are to be located are so small that it will be necessary to remove the cover of the Petri dish, and to examine it fearlessly with the agar surface exposed. If carefully done, the contaminations resulting are practically negligible. It will be necessary to use an objective with a long working distance and the $\frac{1}{4}$-inch or $\frac{1}{5}$-inch is preferable. A rough examination, where the spores are large, may be given by inverting the dish and cover, making the examination from the bottom, and then the location of spores may be indicated by ink marks.

Establishing pure cultures: subcultures. The process of transplanting bacteria, spores, or mycelial masses from an isolation culture to sterile tubes of prepared media is properly that of establishing pure cultures. Frequently it is desirable to make a large number of such subcultural transplantings to be used as the *stock cultures* from which, in future, any necessary series of experiments may proceed.

Under ordinary laboratory conditions, tube cultures may begin to dry out in from six weeks to several months, and must therefore be renewed or transferred. This consists merely in inoculating fresh tubes from the old cultures. A record of such transfers is, for physiological purposes at least, important, and may be indicated on the label, or in the record book.

In making transfers and in examining any tube culture, it is well to flame the plug lightly before removal, otherwise particles of dust from the surface may fall into the tube and contaminate it. The flaming should be momentary, and if the tube is turned so that the plugged end is distant from the operator, it will be easy to blow out the flame. The cork should be removed slowly so that there may be no rush of air into the tube, thus bringing contaminating dust particles. It is needless to say that wherever possible tubes should be held horizontally, or as nearly so as the contents will permit.

FIG. 9. CULTURE OF *PLEUROTUS OSTREATUS* JACQ. (From a Tissue Fragment)

Storage of cultures. In general, it is not well to store tube cultures in a damp place. If moisture is constantly in contact with the glass, or extends through the cotton plug, bacteria will readily enter the tubes. Again, under such circumstances fungous spores may also germinate, the mycelium may grow through the plug, and fruit on the lower side; thus spores will drop into and contaminate the culture. When the plugs become wet during sterilization, particularly those closing flasks of media, the flasks should be re-sterilized after the plugs are dry, or after fresh plugs are inserted. When placed in storage, a paper cone may be placed over a few tubes or a crate, or under some circumstances, particularly where it is desirable also to prevent rapid evaporation, one may employ the rubber caps which may be obtained for this purpose. A refrigerator is desirable whenever cultures are to be maintained fresh for a long period. In this case the ice chamber should have no connection with the storage chambers. Small compartment cases, such as sectional bookcases, are very serviceable for storing cultures away from the dust, under laboratory conditions. The culture room (Fig. 14) is cleaner when the cultures are stored elsewhere.

Sealing cultures. In order to seal the tubes permanently, sealing wax may be used after pushing the plug in somewhat below the level of the glass. Ordinary beeswax is also effective if a little sterile paraffin is first poured over the plug and permitted to harden. The length of life of a culture may sometimes be preserved in this way for several years.

If the cultures are placed in a damp place, as in a closed box or case, with a surface of water evaporating, so as to diminish the loss of water from the tubes themselves, it would be well to wipe out the case carefully with a disinfectant before use. Where it is desired wholly to prevent evaporation under normal conditions of aëration a different method is necessary. The cultures may be put into a clean beaker or tin vessel fitted with a zinc screen, or cross wired with copper, serving to separate the tubes from contact one with another. After thoroughly flaming the corks the vessel of tubes may be placed in a small dish or plate of water containing a little potassium dichromate and the whole covered with a clean bell glass.

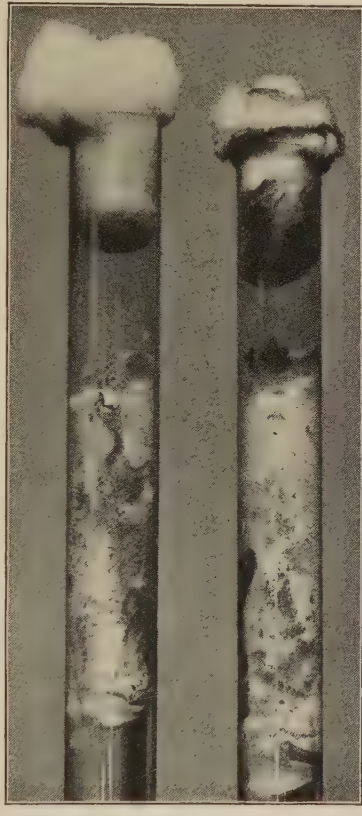


FIG. 10. CULTURE OF *POLYPORUS SULPHUREUS* (BULL.) FR., A SPECIES TOUGH IN TEXTURE. (By Tissue Fragment Method)

Cultures by sporophore fragments. In his studies upon *Agaricus campestris* the writer ascertained that fragments of the inner tissue of the hymenophore of this fungus placed upon a sterile nutrient medium, such as bean pods, sterile compost, soil, etc., would readily develop a vigorous mycelium. In order to secure cultures of this particular species promptly, it was necessary (1) to use proper sterilization and

antiseptic precautions with all material used ; (2) to take fragments from a developing (growing) hymenophore and not from one mature or decaying ; and (3) to employ a suitable nutrient medium. Under such conditions growth is practically invariable (Figs. 9, 10), unless bacteria have previously gained access to the mushroom or the culture accidentally becomes contaminated.

This method, or what was practically the same, has doubtless been occasionally resorted to much earlier for obtaining cultures of a few fleshy fungi, though practically no attention has been bestowed upon the method. The method is, however, capable of being used, and has frequently been used, in securing cultures from sclerotial stages, and the writer has often employed it in obtaining cultures of such stages of certain Sclerotinias. No attempt, however, had previously been made to determine its general applicability. During the past few years this method has been employed with a great variety of fungi, — Discomycetes, certain Pyrenomycetes, and a considerable number of Basidiomycetes, among which were forms widely different as to relationship, texture, and habitat. A record was kept of the trials made with sixty-nine species of Basidiomycetes, and of these, forty grew promptly on the media first employed. The method is especially serviceable in securing cultures of forest-tree fungi and other fleshy or woody forms the spores of which may germinate only with great difficulty.

CHAPTER II

TECHNIQUE OF FIXING, IMBEDDING, AND STAINING

CHAMBERLAIN, C. J. Methods in Plant Histology. (2d ed.) 262 pp. *87 figs.* 1905.
LEE, A. B. Microtomist's Vade Mecum. (6th ed.) 538 pp. 1905.
ZIMMERMAN, A. (Transl. by J. E. Humphrey.) Botanical Microtechnique. 296 pp. 1893.

I. FIXING

The purpose of a fixing agent is to kill and fix, or render permanent, the structural relations of the cell and the associations of cells in tissues. The finer protoplasmic structures are readily disorganized and lost for study, if not carefully fixed by special agents. Moreover, adequate fixing is necessary in order to prepare tissues to show properly the differential effects which may be gained by staining. It is well, therefore, to fix by one or more of the best methods such material as may be valuable for minute microscopic study. This, however, in no way precludes the desirability of studying material in a living condition also, — whenever that is possible.

The material to be preserved should be plunged into the fixing solution in a condition as fresh as possible, so that no changes may occur subsequent to removal from the natural substratum. Great haste is often necessary with delicate fungi in order to avoid drying out. It is well always to use an abundance of the fixing liquid. With osmic and chromic acids one should often employ as much as fifty times the quantity of the liquid as of the material, while with alcohol and formalin, fully three times as much liquid as material. In all cases, the object, if large, should be cut into pieces as small as practicable, in $\frac{1}{4}$-inch cubes or less.

Fixing methods and fixing agents are numerous, and the method or agent to be selected will depend upon the kind of study for which the material is desired. One method will be applicable when histological differentiation is the chief end sought, and when a study

of the fungous hyphæ within other plant cells or tissues is desired; while an entirely different method may be essential if the investigation is to concern itself with more minute cytological details.

Even when material is to be used for immediate casual study it is often necessary to kill and fix it on account of the greater ease with which the subsequent operation of staining may be performed. In the examination of hyaline filamentous fungi it is unnecessary to use any but the simplest methods of fixing on the slide. It has been found desirable to treat such hyphæ for a minute or two with a few drops of a 3 per cent solution of acetic acid. This treatment will also generally dispel bubbles of air. The acid should be well washed out with water before using basic stains. In the same way a 3 per cent solution of potassium hydrate or a weak solution of chloral hydrate will often give good results, — the former, particularly, if the material has suffered any drying out and needs restoring by the swelling process to which the hydrate is adapted.

Alcohol. The fixing qualities of alcohol are well known. When employed alone it is usually recommended to use either very low or very high grades of this agent, and it is serviceable only for gross work. Of the lower grades, 15 to 25 per cent are generally used, for at this concentration little harm will result from the effects of diffusion currents. When the higher grades are used, those from 96 per cent to absolute alcohol are preferable, in order to effect rapid penetration and fixing. Where the weaker grades are employed first, the process is also essentially one of dehydration. The size and consistency of the material will determine the length of time that the object should be left in the lower grades. It is usually left in each lower grade from two to four hours and in each higher grade from four to twelve hours. If one begins with 15 per cent alcohol, the material should subsequently be passed through 30, 50, and 70 per cent, and for safety in hardening 85 per cent, and finally 95 per cent may also be used. Material that is to be kept for any length of time should, however, be stored in from 65 to 75 per cent alcohol, since the higher grades are more apt to render it brittle. If material is fixed in from 96 per cent to absolute alcohol, it may remain at this concentration for from twenty-four to thirty-six hours, and then, if storage is desired, it should be passed back to the weaker grade mentioned.

Corrosive sublimate. Corrosive sublimate is always an excellent killing and fixing agent for histological staining. It may be used as a concentrated aqueous solution, to which, also, the addition of about 1 per cent of acetic acid is often helpful. Whether the material is a fleshy sporophore, or a piece of host tissue penetrated by hyphæ, it should remain in this fixing agent for about twenty-four hours, or until the tissue is distinctly white-opaque. The material is washed for an hour or two in water, and then carried through the grades of alcohol, 30, 50, and 70 per cent, and eventually stored in 65–75 per cent. If not immediately imbedded, it is well to change the 70 per cent alcohol several times in order better to remove the sublimate. Sometimes it is necessary to add a little tincture of iodine to the alcohol in order to more thoroughly remove the corrosive sublimate. If this is done, the liquid should be changed as often as it is discolored by the material. It is also claimed that after corrosive sublimate the material should not long be stored in alcohol, as such material will readily become brittle.

It is often preferable with fungous tissue to use a concentrated solution of the sublimate in 96 per cent alcohol, to which it may also be well to add 1 per cent acetic acid. This mixture penetrates more readily and is more valuable for cytological work than the aqueous solution. Objects thus fixed are transferred after from a few minutes to twenty-four hours to lower grades of alcohol, and washing may be effected by a few changes at the grade used for storage.

At laboratory temperatures mercuric chloride is soluble in water to the extent of about 5 to 6 per cent, and it is much more soluble in alcohol. If it is desired to use stronger solutions of the mercuric salt, it will be necessary to add to the solution some chloride, such as sodium or ammonium. As will be seen later, both the carmine and anilin stains may be used after corrosive sublimate, and the mixtures of this agent are especially good for fixing parts of any of the fleshy fungi.

Chromic acid and chrom-acetic acid. Solutions of chromic acid from .5 to 1 per cent are sometimes used for fixing fungous material; but in general it is so much less valuable alone than in combination with acetic acid of less or equal strength that the combination should be employed. Wash and dehydrate as for the next fixing agent.

Chrom-osmo-acetic acid. This mixture, commonly known as Flemming's solution, is very satisfactory for cytological work with plant tissues. It is particularly desirable as a fixing agent to precede the triple stain, also iron hæmatoxylin ; and these are two of the best cytological stains. As commonly employed, the Flemming solution varies greatly in strength. The weaker solution is ordinarily to be recommended. This should include as an aqueous solution chromic acid from $\frac{1}{4}$ to $\frac{1}{2}$ per cent, osmic acid $\frac{1}{10}$ per cent, acetic acid $\frac{1}{10}$ per cent. It is possible, however, to employ the solution at least twice as strong as the formula given, and it is convenient to make stock solutions of each substance rather than to make up at one time a large quantity of the fixing fluid. Moreover, the stock solutions mentioned may be so prepared as to serve for any strength of the Flemming which may be required. Stock solutions should be as follows :

Chromic acid	1 per cent
Osmic acid	1 per cent
Acetic acid	1 per cent

In order to prepare the weaker fluid, the following quantities will be required :

1 per cent chromic acid . . .	25 cc.
1 per cent osmic acid . . .	10 cc.
1 per cent acetic acid . . .	10 cc.
Water	55 cc.

Stock solutions are very desirable on account of the fact that the Flemming does not keep well, especially when constantly opened for use. Any solution containing osmic acid turns black promptly upon contact with certain organic material or dust. This effect is facilitated by light, although light alone is noninjurious. It is advisable, however, to store the osmic acid in a brown bottle, or to keep it from the direct sunlight.

Ordinarily, material should be left in this mixture from twenty-four to forty-eight hours, and it should then be washed in running water two to four hours and finally passed through the different grades of alcohol beginning at 15 or 30 per cent until the desired storage grade is reached, or until the material is thoroughly dehydrated, if it is to be immediately imbedded. After the use of the Flemming mixture, however, it is often necessary to decolorize the

material. The decolorization is best effected when the material is in 70 per cent alcohol, and during the dehydration process. The simplest method is to add to three parts of 95 per cent alcohol one part of hydrogen peroxide and allow the material to stand in this mixture from twelve to twenty-four hours. It seems to be less injurious to decolorize in mass than eventually to decolorize the sections on the slide, just prior to staining.

Alcoholic mercuro-nitric acid solution. This fluid should be more generally employed with the fungi, since it penetrates well, and may be advantageously followed by hæmatoxylin, anilin, and carmine stains. Gelatinous masses of spores remain intact fairly well in this. About 300 cc. may be conveniently made up as follows:

Water	270 cc.
96 per cent alcohol	30 cc.
Glacial acetic acid	2 cc.
Nitric acid	5 cc.
Corrosive sublimate	10 grams

Material should remain in this agent from one to six hours, then it may be passed through grades of alcohol to 70 per cent, where several changes of the liquid should be made.

I have not found picric acid, or combinations of this with mercuric chloride and other agents, satisfactory for work with the fungi.

Formalin is, of course, a good general preserving liquid, but it is not practicable when imbedding methods may afterwards be employed.

II. THE PARAFFIN PROCESS: INFILTRATION AND IMBEDDING

Material which is to be sectioned by means of the microtome is now far more commonly imbedded in paraffin than in celloidin or collodion. Some chief advantages claimed for the paraffin method are: (1) better penetration of the imbedding substance, permitting more uniform and thinner sections; (2) facility in cutting, together with ease of preserving the sections in serial order; (3) convenience of the paraffin ribbon in the further processes involved.

Assuming that the substance which is to be imbedded is stored in alcohol, it becomes necessary, as the first step, to dehydrate thoroughly by treating with 90 per cent alcohol during about twelve

hours, and then with absolute alcohol. It is desirable to change the absolute alcohol once, permitting the material to remain each time from four to six hours.

The infiltration methods, that is, methods by which the penetration of paraffin into the tissues and cells is effected, are various, and biologists do not agree as to which is most practicable. The chief difference lies in the nature of the solvent employed to precede the paraffin. After having tried for years chloroform, xylol, and cedar oil in turn, it is preferred with the majority of tissues to employ the chloroform method, — a method at once simple and sure. It is as follows:

The chloroform infiltration method. The material from absolute alcohol is put into a mixture of equal volumes of absolute alcohol and chloroform. It is permitted to remain in this mixture for from twelve to twenty-four hours, and then pure chloroform is substituted. In the pure chloroform readily penetrable tissues will soon sink and will be thoroughly penetrated within twenty-four hours. Many tissues will require two days, and two days may be most desirable. At the end of this period, whether the tissue is sunken or not, it is poured out into an open dish (small porcelain vessels 2 or 3 centimeters broad and deep being very desirable), and into this dish is cut more than enough hard paraffin (53° to 54° C.) finally to cover the material with paraffin alone, or, better, sufficient in which finally to imbed the material. These dishes are then put into the oven at 55° to 56° C. and the chloroform evaporates within a day or two. If stirred once or twice, it will evaporate more promptly, and the material is then in excellent condition to be imbedded in the papers or special imbedding trays commonly used. Paraffin used in this process, if the chloroform has all evaporated, is excellent from the standpoint of viscosity, and consequently it will cut more evenly than fresh paraffin.

Cedar oil and xylol infiltration. Some prefer to use cedar oil as a solvent with the paraffin. That method, however, is somewhat more taxing and seldom to be recommended. The cedar oil is more difficult to remove from the tissues, and I have found it desirable only in cases where the material is exceptionally brittle. When cedar oil is employed, it seems desirable to pass from absolute alcohol to a mixture of cedar oil and alcohol, the tissues

sinking from the alcohol into the cedar oil, and this indicates the time when the mixture may be replaced by pure cedar oil. After remaining in the cedar oil for from twelve to twenty-four hours soft paraffin may be added. In from twelve to twenty-four hours hard paraffin may be used, and after a similar period the material may be imbedded in trays in fresh paraffin. It is desirable in this process to have the material held in little wire-meshed ladles, and thus the change from one grade of infiltrating agent to another is effected by a transfer of the ladle from one vessel to another. In each case the ladle is thrust into the liquid sufficiently to cover the bowl and material. The cedar oil is then more readily displaced, sinking to

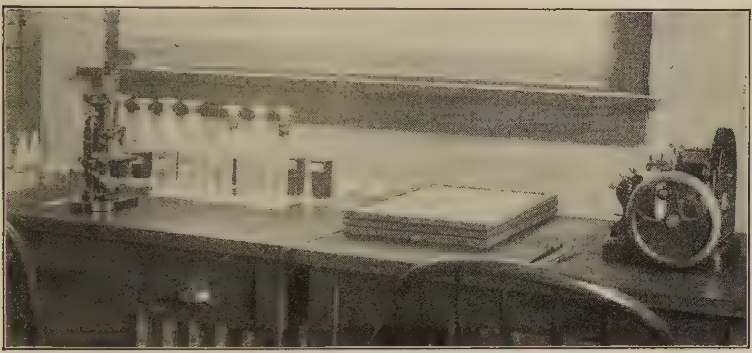


Fig. 11. A Desirable Outfit for Sectioning and Staining

the bottom, and there are fewer difficulties in sectioning on account of electrification, which is intensified by the presence of oil.

Xylol is also employed in infiltration, but with some tissues there seems to be a peculiar optical effect produced, and it has no peculiar advantages for this purpose.

Sectioning. When the objects are imbedded they should be so disposed that each, or each group, is far enough from those adjacent to permit of its being readily cut out and attached to the object carrier. When melted to the carrier careful orientation is given. Sectioning is a simple operation with material properly infiltrated, with a sharp razor or microtome blade, and with the laboratory at living-room temperature. Very tough or carbonaceous fungi will never yield satisfactory sections by the paraffin method, but the great majority of the parasitic fungi may be thus treated. There

is a tendency to make the sections too thin when this method is employed. Some thin sections will usually be required, but for such studies as the distribution of the fungus in the host, and the forms and relations of fruiting organs, thicker sections are preferable.

Attaching sections. Since the paraffin method is here presented in some detail, a few indications with reference to fixing sections to the slide and the further manipulation of the material will be requisite. A *minute* drop of egg albumen preparation[1] is first rubbed over that portion of the slide to which the sections are to be affixed. Add a few drops of water from a pipette, arrange the sections or ribbon exactly as may be desired on the slide, allowing for expansion to their normal size, and place the slide immediately in the paraffin oven, that is, at a temperature which will just melt the paraffin (Strasburger's method). In two hours the slides will be ready for removal and for the subsequent processes. The method mentioned is simpler and better than the one in which more water is added when the sections are laid on the slide, the slide warmed over a flame until the sections spread out, the water drained off, and finally the slides set aside from four to twenty-four hours to dry in a warm place. In either case, when the slides are thoroughly free of moisture, they are passed into the xylol for a few minutes, then into absolute alcohol, and to such other grades as are necessary prior to staining. In all of these processes Coplin's staining jars or other similar vessels are desirable. Care should always be taken to remove every trace of paraffin before proceeding further.

III. STAINING

Filamentous fungi. It is often necessary to employ staining methods in an examination of hyaline filamentous fungi, even if the observation is merely for the provisional determination of the fungus at hand. This is particularly true in an examination of certain mold or hyphomycetous fungi. Such fungi, and particularly the aërial parts of such fungi, should be well teased out in a drop of weak acetic acid, or sodium hydrate in 10 to 20 per cent alcohol, on the slide. This killing agent is drained off by means of filter paper, the preparation washed, and then it may be stained

[1] Egg albumen, 50 cc.; glycerin, 5 cc.; and salicylate of soda, ½ gram.

with a solution of eosin. A $\frac{1}{2}$ per cent aqueous solution will suffice, but alum eosin ($\frac{1}{2}$ per cent alum) is even better. Unless the object is first killed, as by being treated with acid, the stain will very readily disappear, or become indistinct, when mounted in glycerin or in glycerin jelly. A $\frac{1}{2}$ per cent solution of fuchsin may also be used. Hyaline fungi to be preserved as glycerin preparations should always be stained, otherwise the fungous outlines will in time become very indistinct.

Many of the fungi may be carefully studied for purposes of identification and for a knowledge of their general structure without the use of stains and staining methods. To this class belong practically all of the filamentous fungi which are not hyaline, that is, those which are flavous, olivaceous, brown, or otherwise colored in such a way that the outlines of cell walls show distinctly when mounted in water, glycerin, glycerin jelly, etc. The most delicate fungi are those which necessitate the use of stains, such as many members of the *Mucoraceæ*, *Saprolegniaceæ*, *Peronosporaceæ*, and other related orders, as well as many mucedinous Hyphomycetes.

It is usually recommended to make up concentrated alcoholic solutions of eosin and fuchsin as stock solutions. Then, as desired, weaker stains may be prepared from the above by dilution with water, the latter, of any strength desired, being kept conveniently in dropper bottles. The staining process is very simple and consists merely in adding a drop or two of the stain to the preparation on the slide, then washing it off with water when the desired effect has been produced. A drop or two of low-grade or acidulated alcohol will usually remove any overstaining.

It has been ascertained that those fungi which are stained only with difficulty by this process are much more readily stained if an acid or an alkaline solution of the stain is employed. Carbol fuchsin is one of the recognized strong stains of this class. This may conveniently consist of a .5 per cent aqueous solution of carbolic acid, to which is added sufficient of the concentrated fuchsin stock solution to make a strong stain.

Fleshy fungi and tissues. Staining processes such as have been already described are very simple when compared with most of those which must be resorted to when the material consists of a fungous tissue, or of other tissue penetrated by a fungus. Loose,

readily penetrable tissues may be stained in mass with a ground stain, but in general it is preferable to stain sections on the slide. Material of the fleshy fungi more often lends itself to mass staining, and this process becomes particularly desirable, moreover, when carmine stains are advised. The carmine stains are most important if the material has been fixed in sublimate mixtures.

A successful method of staining fleshy fungi for histological differentiation has been used by Burt as follows:—Alcoholic material is stained *in toto* twenty-four hours in Mayer's alcoholic paracarmine. When the sections have been mounted on the slide and dehydrated, they are stained for about five minutes in an aqueous solution of fairly strong safranin, and finally washed in water, previous to mounting in water and glycerin. With tissues fixed in sublimate mixtures, the Ehrlich-Biondi-Heidenhain stain has also been found to give effective histological differentiation. This strain should be obtained ready-mixed from Grübler & Co. To 100 cc. of 0.4 per cent solution of this mixture must then be added 7 cc. of a $\frac{1}{2}$ per cent acid fuchsin solution. This stain gives some nuclear differentiation, but it cannot by any means be called a successful nuclear stain. Only small quantities of this stain should be combined with the fuchsin at one time, since its keeping qualities are not good.

A double stain of any standard hæmatoxylin followed by erythrosin eosin or orange G is sometimes to be recommended when material is fixed in alcohol; but, in general, many hæmatoxylin stains are not so valuable for work with the fungi as with the higher plants. Magdala or Congo red may be followed by an anilin blue or green to advantage. A stain of any solution of eosin or carmine followed by a counter stain of nigrosin is often of value. In cytological work more than in any other kind, it is necessary to bear in mind the nature of the fixing agent in deciding upon an effective stain. After sublimate fixing, one of the most successful methods of staining on the slide for the differentiation of cytoplasmic and nuclear structures is one apparently first published by Wager. It is a cumbrous and complicated process in print, but is much simpler in practice. As I have used this stain, it is a slight modification and simplification of Wager's process. The principal solutions needed are:

1. A 50 per cent solution of alcohol containing a trace of nigrosin and acetic acid.

2. Mayer's alcoholic paracarmine.

3. 5 per cent glacial acetic acid in 50 per cent alcohol, to which is added sufficient nigrosin to make it bluish black in the bottle.

4. 50 per cent alcohol strongly acidulated with acetic acid.

The sections on the slide are mordanted for a few minutes in 1. They are then somewhat understained in solution 2, the superfluous stain washed off in 50 per cent alcohol, and the slide placed in 3. In this last it remains until examination shows it to be slightly overstained. It is then washed and decolorized to the desired degree in the 50 per cent alcohol strongly acidulated with acetic acid (4).

Mayer's alcoholic paracarmine, used in this connection, is made by using carminic acid 1 gram, chloride of ammonium 0.3 grams, chloride of calcium 4 grams, and 100 cc. of 70 per cent alcohol. Dissolve the carminic acid by heat if desired for immediate use, then allow it to settle, and filter.

Flemming triple stain. When material has been fixed in chromic acid solutions, particularly in the Flemming chrom-osmo-acetic, then the Flemming triple stain is one of the two most valuable with the fungi, as with nearly all other plant tissues similarly fixed. This stain requires safranin, gentian violet, and orange. The usual method is to stain on the slide for several hours to a day in a strong alcoholic solution of safranin, rinse in 95 per cent alcohol until very little color remains, stain for a few minutes to several hours in gentian violet, wash for a very short time in water, and plunge into a strong solution of orange G for a few seconds. The slide is then treated with absolute alcohol in order to wash out the surplus gentian. Differentiation is effected by treatment with clove oil or with clove oil first, and finally with xylol for fixing, before being mounted in damar balsam. Almost any safranin stain may be used in this combination, but it will often be found that the safranin may be entirely omitted with advantage. By this means the process is also greatly shortened. Perhaps the best gentian violet which may be used in this process is that of Ehrlich, consisting of:

Gentian violet . .	1 part	Anilin oil	3 parts
Alcohol	15 parts	Water	80 parts

The method of procedure with the gentian will depend on whether a chromatic or a kinoplasmic stain is desired. In the first case a short immersion in a strong stain will give best results, and in the latter case it is often well to use only a few drops of the gentian to a tumbler of water. The orange acts rapidly upon well-fixed structures, and often an immersion of a few seconds will suffice. Clove oil washes out the gentian somewhat in clearing, but bergamot oil does not have this effect, and serves rather to fix the stain, so that it may sometimes be necessary to dash the slide with bergamot oil before differentiating with clove oil. In every case, however, considerable experimentation is necessary for the proper handling of this stain.

Iron hæmatoxylin. Where the safranin-gentian-orange is ineffective, iron hæmatoxylin will often give excellent results. With this process the sections are immersed from one to several hours in about a 3 per cent solution of iron alum (ammonia-sulphate of iron). They are next washed well in water and then stained in a 0.5 per cent aqueous solution of hæmatoxylin. The latter is allowed to act until a considerable overstaining has resulted. The slide is then washed and again put into the iron solution until the desired differentiation shall have resulted. It is then dehydrated, etc., as usual. Iron hæmatoxylin will give some brilliant results when the Flemming combination is ineffective. It is usually necessary to considerably overstain the preparations and then to wash out strongly in the alum solution if chromatin differentiation is desired. It is sometimes well to follow this treatment with a slight ground stain of orange G.

After Merkel's solution good results have been obtained by Harper with a double stain of acid fuchsin and iodine green. The same stain has also been found useful after corrosive sublimate by Wager in his studies upon the cytology of the yeasts.

Bacteria. Only a few general directions may be given dealing with some of the ordinary methods now employed for the staining of the bacteria. The concentrated alcoholic solutions mentioned for the fungi are used, and, in addition, a similar solution of gentian violet. These solutions are sometimes made of definite proportion, standard strengths being 1 gram of the stain to 10 cc. of 95 per cent alcohol. These solutions are diluted for use, just as with

the fungi. Carbol fuchsin is also largely employed in the staining of bacteria. The alkaline stain most widely employed is perhaps Loeffler's alkaline methylene blue. This solution consists of:

Alcoholic solution methylene blue	30 cc.
1 per cent solution potassium hydrate	1 cc.
Distilled water	100 cc.

Other excellent stains are Ehrlich's anilin-water fuchsin and gentian violet. These are made by adding to 10 cc. of distilled water an excess of anilin water; this being shaken until no more will dissolve, and then filtered. To such solutions are then added 1 cc. of the saturated solution of gentian violet or of fuchsin.

In order to stain effectively the flagella of bacteria rather complex methods are necessary. No method is satisfactory unless every precaution is taken to have (1) the cover slips thoroughly clean; (2) the organism from a young (twelve to twenty hours), vigorous culture, on a suitable medium; and (3) the bacteria evenly and thinly disposed upon the slip. Where experience has not taught one to what extent to dilute a loop of bacteria for the best staining effects, it is well to arrange the covers in series of from four to five. Place a minute drop of water upon each slip, then diffuse the bacteria from the culture in the first drop, and with a loop from the first drop pass to the second, third, etc., in turn, first diffusing the contents of the loop, then sweeping the needle across the cover and passing to the next. These are dried and fixed to the slip as previously indicated.

There are several important methods of staining flagella. Loeffler's method, or some modification of it, is frequently employed. This, like most flagella methods, involves two chief operations, viz., mordanting and staining. The mordant consists of:

20 per cent tannic acid solution	10 cc.
Saturated solution of ferrous sulfate	5 cc.
Saturated solution of fuchsin, aq. or alcoholic . .	1 cc.

This mordant may be generally used as above, or it may be necessary to add an acid (in the case of certain alkali-producing organisms) or an alkali (certain acid-producing organisms), according to Loeffler, this being done by adding to the mordant a fractional percentage of weak stock solutions of a caustic alkali and an acid.

A few drops of the mordant are placed upon each slip (preferably supported by the cover slip forceps). The slip is held cautiously high above a small flame until vaporization *begins;* the mordant is then washed off with water, followed by alcohol; finally the preparations are stained in anilin-water fuchsin, washed, dried, and mounted in balsam.

The modification of the above stain by Löwit is strongly recommended. This consists in substituting copper sulfate for the iron salt. The preparations are generally mordanted from thirty seconds to three minutes and washed. They may then be stained in the anilin-gentian violet of Ehrlich and the surplus stain washed out in water, 50 per cent alcohol, or acidulated alcohol. Freshly prepared solutions both of the mordant and of the stain should be employed.

PART II

PHYSIOLOGICAL RELATIONS

CHAPTER III

GERMINATION STUDIES

CLARK, J. F. On the Toxic Effect of Deleterious Agents on the Germination and Development of Certain Filamentous Fungi. Bot. Gaz. **28**: 289–327, 378–404. 1899.

DUGGAR, B. M. Physiological Studies with Reference to the Germination of Certain Fungous Spores. Bot. Gaz. **31**: 38–66. 1901.

FERGUSON, M. C. Germination of the Spores of Agaricus campestris and Other Basidiomycetous Fungi. Bur. Plant Ind. U. S. Dept. Agl. Bullt. **16**: 1–43. *pls. 1–3*. 1902.

Requirements for germination. With regard to their requirements for germination, the spores of fungi show very marked differences. It may be possible to group the fungi in three categories, based upon their minimum requirements, although it is very probable that the limitations of these classes may not be fixed with any degree of definiteness. These classes are as follows:

1. Those which may germinate in moist air or in water.
2. Those which require a nutrient solution.
3. Those which require a special stimulus.

Where the spore germinates in moist air or in distilled water it is merely the absorption of water, under external conditions favorable for growth, which suffices to give the necessary incitation. In other words, the spore is then undoubtedly provided with its own food material. Many parasitic fungi evidently belong to this class. No nutrient substance is known to enhance the germination of spores of the Uredinales, Peronosporales, and some other obligate parasites. This statement is necessarily put in this form on account of the fact that many observers have employed ordinary tap water in their

experiments. Conidia, æcidiospóres, and uredospores ordinarily germinate best immediately after maturity; but oospores and teleutospores generally require a period of rest. It is certain that a few saprophytic fungi may also germinate in distilled water. This is true of *Œdocephalum albidum*, some species of Botrytis, and certain hyaline-spored Basidiomycetes.

In general, the saprophytic fungi seem to require a nutrient medium for germination; and the percentage of germination depends largely upon the direct food value of the medium, the perfect food affording the best germination. This is particularly true for Penicillium, Aspergillus, certain Mucoraceæ, and probably many other fungi. Moreover, plant pathologists generally recognize that most of the imperfect or ascomycetous parasitic fungi germinate most readily in nutrient solutions. Certain of these fungi germinate best in infusions or decoctions of the host plant. Excellent germination may occur in a solution containing a single nutrient, as in sugar solution, glycerin, a nutrient salt, etc. Such cases may, perhaps, justly be classed among food stimuli.

It is known that many parasitic phanerogams require a special stimulus of the host plant before germination may be incited, and it is reasonable to believe that similar instances will be found among the fungi. According to De Bary, the hoof and feather fungus, *Onygena corvina*, requires such a stimulus. Very little special work has been done along this line of inquiry, and interesting results may be expected, particularly with species which have thus far proved refractory under the usual methods of culture. Miss Ferguson has determined that while *Agaricus campestris* may germinate more or less erratically in many nutrient media, or with special stimuli, the best and most constant germination yet secured is obtained by placing in the culture drop a few strands of the growing hyphæ of the same fungus. In such cases, as a rule, a germ tube of a length not greatly exceeding the diameter of the spore is emitted, but no further growth results unless the spores are transferred. This stimulation occurs whether the medium employed is a nutrient solution or distilled water. These results I have been able to confirm repeatedly. Moreover, I have found that a similar stimulus to germination is afforded by placing in the culture drop a fragment of the fresh tissue of the sporophore. The latter is able to

develop a new growth upon which the stimulus, for the most part, depends. In some instances germination has been secured in an infusion (implying no cooking or sterilization) of the fresh tissue.

It has been found by Eriksson that short and sudden cooling has a marked influence to increase the amount of germination in the æcidiospores of the wheat rust, so that a stimulus from the temperature relation may be inferred. It may be well further to inquire if the "resting" period is essential to the germination of certain spores. If resting spores might be forced into germination by special stimulation, pathological work might be greatly facilitated, and material made available for valuable cytological studies.

Methods of study. Studies in the germination of fungous spores in solutions, or in water, are best made by the use of the hanging-drop culture method generally inappropriately called the Van Tieghem cell. This method consists essentially in sowing the spores in a drop of the desired medium on a cover glass and then inverting this cover glass over a glass ring cemented to a glass slip. The old method of using slides with drop depressions in them is not so satisfactory, and cardboard rings give unreliable results. It is necessary to give the details of the method referred to at considerable length. For ordinary purposes I have found it desirable to use glass cylinders of 15–18 mm. internal diameter and 9–10 mm. high, preferably 16 × 10 mm. Xylonite rings produce products in the cell which may be injurious. Rings of such size as indicated provide an abundance of oxygen, and with them the 18 or 20 mm. square and round covers are available. Round covers are preferred, since fewer accidents occur in using them. Slips and rings must first be carefully cleaned by the process previously mentioned. In some very delicate experiments, where even the vapor from vaseline should be avoided, rings may be placed in a Petri dish provided with filter paper in which holes are cut for their insertion (Fig. 13, *b*).

The rings are cemented to the slips by means of beeswax alone, or beeswax with the addition of a small amount of vaseline.[1] For

[1] Waterproof permanent cements may also be employed, but they are not generally satisfactory.

very careful work purified beeswax and white vaseline should be used. As a matter of convenience, two rings are usually cemented to the same slip. To make the cells, the wax is kept melted, the slide is slightly heated in the flame, and by means of the forceps the ring is passed through the flame, after which one edge is dipped lightly into the melted wax, then quickly placed upon the slip. If the wax is too hot, it will be necessary to touch the ring several times to the melted wax, then raise it high enough to cool somewhat. When the wax is cool the free edge of the cylinder is provided with a ring of vaseline by inverting the cell over a slip, or shallow watch crystal, upon which there is spread a thin layer of melted vaseline (Fig. 12). The cell should be momentarily held in this inverted position, or rested in this position on a rack, in order that the ring of vaseline will have some depth. By means of the vaseline ring the cover is, at the proper time, cemented firmly to the glass cylinder. If the temperature at which the cultures are to be incubated differs considerably from that at which the cells are made, it has been found well to make with the back of a scalpel a small nick in the vaseline ring, through which nick the expanding air may pass when the cultures are placed in the thermostat, or culture incubator. Afterwards they may be permanently sealed by slight pressure with scalpel or needle. A drop of the culture fluid to be used is placed on each cover glass, and about half a dozen drops of the same fluid are placed in the bottom of the cell. A small glass rod is the only satisfactory dropper for the first-mentioned work. The drops are inoculated with a few spores by means of a platinum needle, massing or bunching of the spores being prevented as much as

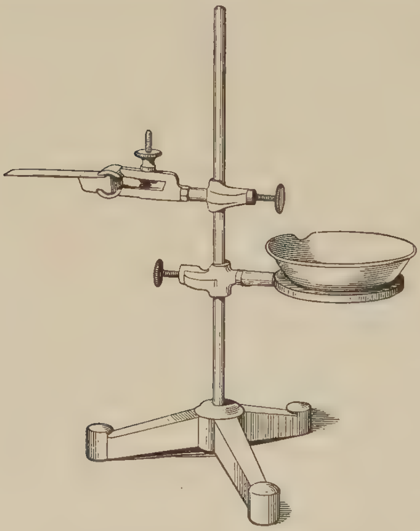


FIG. 12. STAND AND DISH FOR BEESWAX

possible. It is sometimes desirable to distribute the spores previously in a drop or small quantity of water, otherwise one may get too many in the culture drop. The covers are then inverted over the glass ring and pressed down so as to leave only one minute unsealed area.

It is an unwise and an inaccurate plan to use in the bottom of the cell any other liquid than that used in the culture drop. This must be so in order that there may be no differences of vapor pressure, and consequently no evaporation from drop to liquid below, or vice versa. For instance, it would be manifestly absurd to test germination in a drop of, say, 5 per cent alcohol above if there were only pure water below. If there is danger of contamination below, and consequent interception of the light, thorough sterilization must be given beforehand. If the drop cultures are made as soon as the slides are prepared, sterilization should not be necessary, since all parts are flamed. Sterilization may be given at any time, however, previous to the ringing with vaseline. It is usually sufficient to sterilize the cells in a dry oven at a temperature of from 110° to 115° C. This temperature melts the wax, but if the slides are level, there is no danger that the cells will slip. A temperature much higher is not to be recommended. Another convenient method of sterilization is by means of formalin. The cells are filled with a solution of from 3 to 5 per cent formalin, and this is allowed to stand for half an hour; then on being rinsed with distilled water, again filled with the water, and left for ten minutes they will be found sterile. The cells should then be inverted and dried before the ringing with vaseline is effected. By this process some cells will become disconnected; but if the cementing has been well done, this is a matter of small importance.

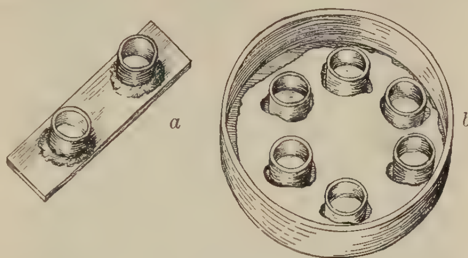


FIG. 13. RINGS FOR DROP CULTURES
a, cemented to slide; *b*, in Petri dish with filter paper

Since it will often be found desirable to invert the slides and cells to prevent contamination while awaiting use, the work should be

done in a culture room (Fig. 14), and tin racks should be provided. Miss Ferguson[1] has devised a convenient stand for holding slides in cell culture work; and since in many laboratories where infection experiments are made, or where physiological work is done, large numbers of these cells may be used, this stand becomes a very useful device. It has been described as follows:

FIG. 14. A SMALL CULTURE ROOM, CONVENIENT AND EASILY CLEANED

A stand for hanging-drop cultures. A stand for supporting slides when one is using the Van Tieghem cells should be made of such material and in such a way that it will neither burn, warp, nor melt upon being heated, for it is often desirable to sterilize the cells before making up the cultures. It should also combine economy of space with ease of manipulation. All these points are characteristic of the little piece of apparatus which I have used. . . . .

This stand consists, as will be seen from the photographs . . . , of a series of trays placed one above the other. Each tray was made from a single piece of tin without the use of solder. The tin measured $13\frac{1}{4}$ by $3\frac{7}{8}$ inches after it was hemmed. This was folded on the sides just as one folds a piece of paper in making the boxes described by Lee (1896) for imbedding material in paraffin. A strip $1\frac{1}{8}$ inches wide along both ends and on one side was bent up at right angles to the rest, so that a box open at the top and along one side was formed, which measured 11 by $2\frac{3}{4}$ inches on the bottom. The double, triangular, carlike projections formed at the two corners were folded along the back and secured by means of rivets. The tin was then cut, or slashed, $\frac{3}{8}$ of an inch deep, 1 inch distant from either corner on the back. Similar cuts were also made at the corners, and three equally distant from each other and from the outer edges were made on either end. The segment

[1] Ferguson, M. C. Bureau Plant Industry, Bullt. **16**, *l. c.*

of tin along the middle of the back and those next to the free outer segments on the ends were folded in until parallel with the bottom. These act as a shelf on which to rest the next higher tray. The outer and innermost segments at both ends were bent outward, forming projections which are very useful in lifting the trays. The second segment from the corner at either end was bent out at right angles to the side, and then the outer portion of it was again turned up until it was parallel with the position which it formerly occupied. These, with the segments at both corners along the back, which were left erect, prevent the next higher tray from slipping or sliding. It was found desirable to cut the bottoms of the trays out, since the rapid absorption of heat by the tin has a tendency to increase the condensation moisture on the cover glasses.

For convenience in use it is necessary that trays be about $\frac{1}{4}$ inch narrower than the slides are long. Unfortunately, the slides thus extending over the edges of the pans are very easily struck, and the cultures thereby endangered when one is putting other material into or taking it out of the thermostat. To guard against such accident, as well as for greater ease in carrying, a bottom tray was made $\frac{1}{4}$ inch wider than the others, and with a back $5\frac{1}{2}$ inches high. This tray had five segments cut at each end instead of four, and these were turned the same as in the other trays, except that the outermost one was bent in to give greater stability. Shelves were made along the back by cutting and folding in the tin at these points. The windows thus formed give free circulation of air. These windows, each $2\frac{1}{2}$ inches long and 1 inch deep, were so cut that if the pieces of tin freed along three sides had been bent straight inward, they would have formed shelves $\frac{1}{4}$ inch higher than those at the ends. But they were doubled in close against the back for an inch, and then turned out until they stood parallel with the bottom of the tray. This gives a little back at the points where the windows occur, and prevents any cultures on the second tray from slipping through these open spaces. For convenience in handling, the bottom was not cut from this first tray as from the others, and it may be used for a support for cultures or not, at the discretion of the operator.

The trays were all made of the same size. Five trays besides the bottom one constitute a "set" as we have used them. Each such set holds 120 cultures, and occupies only 36 square inches of space in the thermostat. The trays may, of course, be made of any length or of any height, the dimensions given are those best suited to the thermostat which we have used. When all the trays have been filled in making up a set of cultures the five upper ones are lifted together and so placed on the lowest pan that their open sides were against the back of this tray.

I am aware that the number of words necessary for describing this little piece of apparatus makes it appear somewhat complicated, but if one will take a piece of paper of suitable dimensions and follow the description given, he will find that the making of a model of one of these trays is a very simple matter.

CHAPTER IV

GENERAL RELATIONS TO ENVIRONMENTAL FACTORS

Benecke, W. Allgemeine Physiologie der Ernährung der Schizomyceten und der Eumycetem (Stoffwechsel). Lafar's Hdb. d. tech. Mykologie **1**: 303–427.

I. SAPROPHYTISM AND PARASITISM

Since the fungi are those classes of plants low in the series with respect to morphological complexity which possess no chlorophyll, they are unable to utilize the carbon dioxid of the air, and like insects and other animals they require their carbon in organic combinations. They are accordingly associated with organic matter, living or dead. The plant pathologist devotes primary attention to those fungi inducing injuries sufficient to be termed plant diseases. Interest is, of course, attached also to any parasitic species; that is, to any which may penetrate and develop within or upon the tissues of another plant, but the nature and extent of the disturbances which result offer the special problems and make necessary the special field of the pathologist.

The habitats of the majority of the fungi are situations in which organic matter is available through the decay of dead things. Indeed the fungi take a prominent part in decay, or the return of organic matter to more elementary combinations. Forest and field, therefore, abound in species, whether evident or not to the popular eye. The fungi associated with decaying materials only are termed **saprophytes** (*metatrophs*). Theoretically, the pathologist is not concerned with this class of organisms. On the other hand, a very considerable part of the fungi obtain their organic nutrients by penetrating a living organism as host and growing in intimate association with its body. Such fungi are termed **parasites** (*paratrophs*). The parasitic fungi are, for the most part, parasitic upon plants, although small groups are confined very largely to insects, and a few species affect higher animals.

Considering the fungi as a whole, there is necessarily no sharp line of demarcation between the saprophytic and the parasitic habit. Some organisms which attain their best development as parasites may, if occasion demands it, sustain themselves saprophytically, or they may normally undergo a portion of their existence as saprophytes. The converse of this is also true. With respect to this habit four subdivisions may be recognized.

Obligate parasites are, practically speaking, entirely dependent upon other living things for requisite conditions of growth and particularly, perhaps, for the organic nutrients.

Obligate saprophytes grow upon nonliving substances and are unable to penetrate living tissues.

Facultative saprophytes are organisms which normally pass through life as parasites, but which are capable for a time, or in certain stages of development, of a true saprophytic existence.

Facultative parasites are saprophytes which only occasionally, or under very special conditions, may become parasitic.

In making these distinctions it should not be assumed that special weight is given to the form of the organic food materials utilized by the fungus, since it is quite probable that a parasite on the one hand and a saprophyte on the other may secure from its host or from the substratum precisely the same compounds. Biological relations should be regarded as most important. For general descriptive purposes and for biological discussion the classification mentioned above is a matter of convenience, but opinions would vary greatly if it were necessary to apply this specifically.

The group in which obligate parasitism seems most clearly defined is that of the rusts, Uredinales. It would be useless to try to cultivate these fungi in nonliving substrata, that is, in artificial cultures. The germination of the spores alone may proceed apart from the host. In such groups as the Chytridiales and the downy mildews, Peronosporaceæ, the majority are obligate parasites; yet a few of the former order, and species of Phytophthora in the latter family, have been grown on dead substrata. The smuts, Ustilaginales, and the plum pockets and witches' brooms of stone fruits, Exoascaceæ, are strictly parasitic, although upon artificial media the conidia of many species may sprout vigorously. The surface mildews, Erysiphaceæ, are doubtless also properly classed here.

The obligate saprophytes include many of the mushrooms, Basidiomycetes, and common molds of diverse families.

Most of the important disease-producing fungi popularly known as leaf spots, cankers, stem rots, etc., are capable of vigorous growth in artificial culture, and some even produce normal fruit bodies under such conditions. These fungi are commonly Ascomycetes and Basidiomycetes. In nature many organisms belonging to these classes develop and mature their fruit bodies, especially the perfect stages, only after the infested parts are dead and fallen.

The facultative parasites are found especially among the groups mentioned in the last paragraph and also among the black molds, Mucoraceæ. Fungi which are ordinarily common upon decaying logs, or destructive to timber, may occasionally develop as parasites on living trees. The black mold, *Mucor mucedo*, so common in the household, may under certain conditions cause a serious rot of sweet potatoes, and it has been known to injure some plants in the seedling stage. The conditions under which such saprophytes become parasitic are not always clearly understood. In general it is evident that some condition of the environment has operated to render the host plant less resistant, or else the conditions have been such as to develop exceptional vigor in the fungus. Almost as long as fungous diseases have been known there has existed the belief that such diseases in any given host plant are in some way dependent upon a certain lack of vigor in the plant. Practical growers and many plant pathologists have held that vigorous, well-cultivated, and well-nourished plants mean plants resistant to disease. No one would question the general desirability of resistant plants, yet this attitude requires special comment and treatment.

A very large number of the obligate parasites and some fungi less obligatorily parasitic are, or seem to be, specially endowed with the ability to enter relatively vigorous growing organs of the plant. The majority of the fungi, moreover, do not kill immediately the tissues which they invade. All sorts of deformities, including witches' brooms, may appear as a result of the association; but so long as the fungus is rapidly growing, it seems generally to have a well-established relation with the living cells, such that when the invaded tissues die, the fungus spends itself in reproduction.

In contrast to those just mentioned, there is that general subdivision of diseases which we have designated as leaf spots, stem rots, and fruit decays. The fungi producing these affections frequently, though by no means always, kill the tissues as they penetrate the host. In other cases they enter and produce disease only when the affected parts have suffered some injury, overstimulation, or drying out. In the case of fruits they are proverbially destructive when the fruits approach maturity. In other words, a very large number of the fungi here included are not in very close association with living tissues, and are, from several points of view, hemiparasitic. It is to be emphasized, however, that many of our disastrous fungous diseases are included in this subdivision. Now in the case of the strictly parasitic fungi already referred to, it is very doubtful if vigor of the host is alone sufficient to prevent disease. In fact, some of the most vigorous varieties (whether judged by vegetative or fruiting achievements) have been particularly susceptible to certain diseases. Before adopting the view that all ills flee before vigor we must make ourselves clear as to what vigor means. If it is synonymous with resistance to disease, then of course all plants subject to disease under any conditions are nonvigorous. Many wild or native prototypes of certain highly responsive, cultivated varieties when grown side by side with the latter may show more, or may show less resistance to disease, wholly independent of robustness. It does not at all hold that factors which favor the fullest development of the host may not also encourage the fungus. Moreover, factors unfavorable to the host may be similarly unfavorable to the fungus.

Phytophthora infestans, *Plasmopara Viticola*, and *Cystopus candidus*, on some of their hosts, — the potato, the grape, and the shepherd's purse respectively, — would seem often to be most effective when the host is growing vigorously. Ward has suggested from experiments with the rust on brome grass that any hindrance to free nutrition of the host is likewise a means of inhibiting the fungus.

In the case of fungi whose weapons for attack are most effective where the plant is least alive, so to speak, — as when the leaves have been injured by drought or other causes, or when the fruit is maturing, — it is then clear that any environmental factor

promoting a healthy growth of all parts of the host throughout the season would decrease disease.

After all, saprophytism and parasitism are terms of degree, and organisms are classed as possessing the one habit or the other simply upon general evidence, or macroscopic appearances. It is quite possible, however, that in an ultimate analysis of the association of host and parasite, or of the method of fungous attack, many organisms now regarded as parasitic would be found to show a true saprophytic habit. It is possible that such organisms may gain entrance to the host through injuries; in other words, establish themselves in association with dead cells. By growth in these cells the excretion of acids and other diffusible products might bring about death in other cells in the vicinity, to which the fungus eventually spreads. So far as the actual presence of the fungus is concerned, therefore, there would be no direct association with a living cell in order to secure organic nutrients. This method of attack has been demonstrated to be that followed by *Botrytis cinerea*, a common greenhouse fungus.

II. GENERAL RELATIONS TO CLIMATOLOGICAL FACTORS

Experiment and observation alike demonstrate that the abundance of a very large number of fungous diseases is directly connected with or conditioned by climatological factors. With respect to conditions in the open, climatological factors are generally understood to mean water (moisture), light, temperature, and wind. These factors may affect independently host and parasite, and they may affect the interrelations of these organisms. Moreover, it is often difficult to interpret what factor is finally operative, or it is difficult to determine what are direct and what indirect effects of these environmental conditions upon host and fungus. In many instances it would be merely hypothetical with the data at hand — largely observational — to do more than designate certain apparent or proximate causes.

Moisture. Many fungous diseases are directly associated with abundant precipitation, or a humid atmosphere. There is no more conspicuous example of this than the brown rot of stone fruits — a disease which, in moist weather, has repeatedly crippled the peach industry. The association of epidemics of such diseases as

black rot of the grape, apple scab, and late blight of the potato with humidity is a matter of almost annual record.

Moisture generally augments the production of spores, and it is, of course, essential to the germination of these. It may at times, however, have another effect, — that of promoting the susceptibility of the host to attack. The potato appears to be more readily affected by the Phytophthora when it has at least sufficient water for vigorous growth. Kühn observed that there are two stages of growth when the plant is most susceptible, first, when the plant is young and tender, and second, when tuber formation begins more vigorously. Ward thinks these two stages correspond to periods of rapid movement of water and soluble food materials.

He has also cited certain conditions under which *Botrytis cinerea* is parasitic, and the suffusion of the host with water is a prominent feature of this case.

It is commonly stated by grape growers that not only is the black rot of this fruit most abundant in humid weather, but that, further, it is more abundant upon vines which have made a vigorous "sappy" growth. This would indicate that moisture acts here also indirectly to render the host more sensitive.

Pseudomonas campestris, producing the black rot of cabbage, gains entrance to its host by reason of beads of water over the marginal water pores of the leaf. These droplets are, when there is sufficient soil moisture, a normal occurrence on cool mornings succeeding warm days. It signifies a state of "guttation," and, practically speaking, means a water way between the external and internal environment.

Smith and Stone (see asparagus rust) have demonstrated an interesting water relation as affecting the prevalence of the rust of asparagus. The fact that chrysanthemum rust may be largely controlled by subirrigation, and carnation rust greatly reduced by the same treatment, is perhaps to be explained simply by the prevention of germination.

An examination of the conditions under which epidemics occur in the case of such fungi as the leaf blight of celery, leaf spot of strawberry, and many others lead to some interesting suggestions. These diseases may disappear during a moist summer, which affords a relatively succulent growth of the hosts. In fact, such

blights mentioned seem to profit materially from severe alternations or contrasts of weather conditions. Moreover, if heavy dews prevail during a warm summer these fungi spread irrespective of precipitation. In such cases it is apparent that injured or drying portions of the plant are at least the first seats of disease. It seems to be true that many crop diseases are commonly most important under conditions of moisture insufficient for most vigorous crop production.

Light. The chief rôle of light in plant economy is connected with the formation of sugar and starch, from which, in large part, the other organic products are ultimately derived. Light, however, calls forth a variety of responses in every green plant, and it may play a direct or indirect rôle in the relation with parasitic fungi. It has long been observed that celery under lath or cloth screens, that is, half shade, is largely free from the early blight. The leaf spot or so-called rust on the strawberry may be similarly controlled through reduction of the light factor with the increased humidity and diminished evaporation generally incident thereupon. It is also reported that the tent cloth is effective against asparagus rust. Ginseng growers in New York and Missouri are employing the lath screen advantageously in the prevention of a serious blight of this plant, due to a fungus which is believed to gain entrance most readily at the margin of the leaf, possibly following a tendency to sun scald in that area. Screening, however, is not advised for strawberries, and it would be available in the home garden, in general, only where such a device may be at will readily interposed or removed. In opposition to these beneficial effects of half shade, we have also abundant observations showing that certain powdery mildews are far more effective as parasites under just such conditions as above enumerated. I have seen wheat under partial shade badly infested with the powdery mildew, which in the central West, at least, is seldom, if ever, seen in the open. Time and again, in that same region, one may observe that in the case of well-watered lawns the mildew of blue grass abounds in a circle rather sharply limited by the heavier shadow areas of trees. Similarly, in the drier West the grape mildew is, as a rule, found mostly on *Vitis vinifera* stock, and in shaded places. The fungus soon disappears from leaves to which strong sunlight is admitted.

Strawberry mildew is also far more abundant in shaded localities. It is a matter of common observation that while cucumbers frequently mildew under greenhouse conditions, yet in the open the cucumber mildew is very seldom observed upon this host, at least in the eastern and central United States. It is claimed that certain greenhouse plants are more subject to the attack of the common gray mold, Botrytis, when partially etiolated, and De Bary, it seems, was able to predispose Petunia to the attack of Botrytis through etiolation.

It is apparent that in so far as screen mechanisms largely prevent the formation of dew, it is probably in large part through this change in the moisture relation that they are important. There may also result a number of direct effects of light, for in the case of strongly etiolated or yellowed and attenuated plants, bud and stem diseases seem frequently to be more common. Very little experimental study has been bestowed upon these relations.

III. SPECIAL RELATIONS TO ENVIRONMENTAL FACTORS

Temperature. Very little work has been done which bears more particularly upon the relation of parasitic fungi to various conditions of environment than to fungi in general. The results of the work available, however, will be of assistance to the student and investigator in using his culture work to the greatest advantage.

The optimum. The optimum temperature for growth of a particular fungus in culture may not be the optimum temperature for spore germination or for spore formation. It is difficult for observers to agree precisely in giving what is termed the optimum temperature for any fungus, since one observer may emphasize the total growth (dry weight), another the abundance of spore production, etc. The optimum temperature as given for the growth of various species of bacteria usually refers to the temperature at which the extent of the colony is greatest. Wiesner has studied in detail the relation to temperature, of (*a*) germination, (*b*) visible mycelium development, and (*c*) spore formation in the saprophytic fungus *Penicillium glaucum*. In the absence of data equally as good for parasitic fungi, the

observations on the above-mentioned organism are here presented in tabular form.

Temperature, ° C.	Time to Germination (Days)	Time to Production of Visible Mycelium (Days)	Time to Spore Formation (Days)
1.5	5.80		
2.0	5.50		
2.5	3.00	6.00	
3.0	2.50	4.00	9.00
3.5	2.25	3.50	8.00
4.0	2.00	3.00	7.75
5.0	1.50	2.90	7.00
7.0	1.20	3.00	6.25
11.0	1.00	2.30	4.00
14.0	0.75	2.00	3.00
17.0	0.75	2.00	3.00
22.0 (opt.)	0.25	1.00	1.50
26.0	0.50	0.99	2.00
32.0	0.70	1.01	2.10
38.0	0.55	2.25	2.60
40.0	0.70	2.50	3.50

In the above case it happens that the optimum for germination corresponds very closely with that for the formation of a visible mycelium and for the beginning of spore production, but this will not hold for all fungi. In general, the optimum temperature for the bacteria and fungi with which the pathologist is concerned would lie between 25° and 32° C., and it is customary to run an incubator in which ordinary cultures are being kept for vigorous growth and development at from 26° to 28° C.

High temperatures. The thermal death points for vegetative cells of the bacteria and fungi have been variously determined to range from 40° to 75° C. As a rule, few fungi will grow above 40°, and to this temperature most of these organisms will, after a time, succumb. Nevertheless, both fungi and bacteria are able in one stage or another to survive considerable extremes of heat and cold. The parasitic organisms in general are vegetatively vigorous within far narrower limits than those of saprophytic origin, which latter are, for the most part, in nature subjected to greater extremes of conditions during the growing period.

It is well known that spores of bacteria, unlike the vegetative cells, are extremely resistant to heat, — an exposure of one or two hours at the boiling point often fails to kill the more resistant forms. Likewise, it has been supposed that spores of fungi are similarly more resistant than the vegetative condition. This has not been found to be true in the case of *Sporotrichum globuliferum*,[1] and it was demonstrated in my laboratory that spores (conidia) of five forms — *Aspergillus niger*, *Aspergillus flavus*, *Penicillium* sp., *Botrytis vulgaris*, and *Rhizopus nigricans* — differ very slightly as to the thermal death point from that of the vegetative hyphæ.[2] Nevertheless, some spores of even parasitic forms are particularly resistant. It would appear that sclerotial-like structures or similar forms are also capable of withstanding high temperatures, but there is no data which can be presented.

Low temperatures. In general, fungi are able to withstand very low temperatures. Few fungous spores are injured at 0° C. It will be found quite generally true that cultures of saprophytic or parasitic organisms may be frozen solid in freezing mixtures without unusual injury. The effects of winter conditions are not ordinarily such as to destroy fungous spores to any great extent.

Light. The ultimate effect of light of different intensities upon organisms may be manifest through injury, change of form, or special stimulation. The immediate cause of the particular influence is always difficult to determine, as is true in cases of the action of most external agents. A considerable number of investigators have studied the effects of light upon the living cells of fungi and bacteria with regard to its injurious action, inhibition, or stimulation of germination, and the effects upon growth and reproductive processes. In general those organisms seem most readily injured by light which are sensitive to many other external stimuli. Pathogenic bacteria and certain hyaline fungi with specially restricted life relations are soon killed by direct exposure to sunlight. Some saprophytic forms are more resistant, and dark-colored fungous spores or hyphæ are far less influenced. Ward made fresh sowings of *Bacillus anthracis* in nutrient agar in Petri dishes, covering the dishes with glass or quartz plates, and

[1] Duggar, B. M. Bot. Gaz. **27** : 131–136. 1899.
[2] O'Brien, Abigail. Bullt. Torrey Bot. Club **29** : 170–172. 1900.

then pasting over the latter a black paper stencil. After an exposure to varying durations of sunlight or to the electric arc, the dishes were placed in the incubator. The resulting colonies developing show that an exposure of six hours to sunlight is sufficient to sterilize almost completely the agar in those areas of the dishes to which sunlight was admitted, corresponding to the stencil mark. He also threw a solar spectrum on cultures similarly made, and upon incubation it was demonstrated that the blue-violet rays are most injurious in their action. Since this killing effect is not evident when the culture is exposed in a vacuum, it would seem that the deleterious action is probably an oxidation effect.

It may perhaps be inferred that light is more important in the destruction of the spores of parasitic fungi than are all other agencies combined. Nevertheless, many spores are well protected against these deleterious effects. However this may be, a large number of fungous spores find hiding places under protecting rifts of the bark, beneath the leaf scales, or in the débris on the surface of the soil, so that an adequate proportion survive the resting period, as a rule, to continue the prevalence of all common plant diseases.

Many fungous forms are wholly independent of the presence of light as a requisite factor in normal development. On the other hand, in darkness the hymenophores of certain species are said to be abnormal in form.

The results indicate that light has an injurious and retarding influence on the germination of fungous spores. De Bary records that certain members of the Peronosporaceæ, notably *Phytophthora infestans*, germinate with difficulty in daylight and not at all in sunlight, and Miss Ferguson and others have confirmed this observation in experiments with *Agaricus campestris* and many other Hymenomycetes. Very little accurate information is at hand relative to the effects of light in the open upon the development of the fruiting stages of fungi.

For all practical purposes in culture work with the fungi, the relation of light is not generally an important one. The studies which have been made, however, should be followed up from a quantitative point of view, for the exact effects of light intensities

or quality upon form and color, metabolism, rate of growth, etc., are extremely important from a general physiological standpoint.

Nutrients. The cultivation of fungi upon decoctions or infusions of organic substances, or upon solid organic substrata, would afford only through a tedious process of comparative study any fundamental ideas of fungous nutrition. The ease with which fungi may be grown in cultures and the use of synthesized culture media have afforded an opportunity for exact determination of the elements required by these organisms. There may be some specific variations, but it is now generally agreed that the majority of the fungi require nine elements, viz., carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, potassium, magnesium, and iron.

Carbon. For most culturable fungi, whether primarily parasitic or saprophytic, carbon is available as grape or cane sugar, glycerin, asparagin, peptone, etc., in fact, in almost any soluble or readily convertible nontoxic form. It is to be inferred that the obligate parasite, as well, utilizes the soluble carbohydrates, peptones, etc., of the host cell, but its exact relations cannot well be determined. Owing to indirect needs in respiration, the nutrient solution must, in order to yield a considerable growth of the fungi, contain a relatively large proportion of carbohydrates.

Nitrogen. Nitrogen may be furnished to the readily culturable fungi in the form of nitrates or ammonia compounds, but in some cases preferably as peptone, casein, or in other organic form. It is probable that the adaptations which result in obligate parasitism have only in part a special relation to the nitrogen food supply. Some fungi may be cultivated only with difficulty, and among these forms certain species are benefited by using as a substratum portions of the natural host (steamed), or decoctions prepared from the host plant. It is, however, possible that this relation is concerned with special stimuli, and has no bearing on the nitrogen factor.

The relation of certain parasitic organisms to atmospheric nitrogen has become unusually interesting. It has been shown by more than one observer that fixation of nitrogen by the various forms of the leguminous tubercle bacteria, *Pseudomonas radicicola*, may proceed in suitable artificial cultures. It proceeds, therefore, without reference to symbiotic association.

Relatively striking results have been obtained by Saida[1] with the parasitic fungus, *Phoma Betæ*. Some data from cultures seventy-five days old with 50 cc. of media are as follows:

PHOMA BETÆ

Substances added to a nutrient salt solution[2]	Cane sugar, in grams	Fixation of nitrogen, in milligrams
Cane sugar	5	·7393
Cane sugar	17	1.1828
Cane sugar (+ $(NH_4)_2CO_3$, trace)	5	1.1828
Cane sugar (+ $(NH_4)_2CO_3$, trace)	10	1.7742
Cane sugar (+ $(NH_4)_2CO_3$, trace)	20	3.5484
Cane sugar (+ $(NH_4)_2CO_3$, trace)	30	6.2097

More recently Ternetz[3] has isolated five endophytic mycorhizal fungi from certain Ericaceæ, all of which have been found to belong to the form genus Phoma. Three of these organisms, viz., *Phoma radicis Vaccinii*, *Phoma radicis Oxycocci*, and *Phoma radicis Andromedæ*, have shown a well-developed capacity for nitrogen fixation in culture, these three mentioned working even more economically than *Azotobacter chroococcum*, the amount of nitrogen fixation in milligrams per gram of dextrose used, being, under the conditions of culture, respectively 22.14, 18.08, 10.92, and 10.66 for the four organisms mentioned.[4]

The mineral nutrients may be supplied in the form of any of the soluble salts, the neutral salts being, in general, preferable. Formulæ for culture solutions are, however, given under nutrient media.

[1] Saida, K. Ueber Assimilation freien Stickstoffes durch Schimmelpilze. Ber. d. deut. bot. Ges. **19**: (107)–(115). 1901.

[2] This solution was constituted as follows:

KH_2PO_4	0.4
$MgSO_4$	0.4
$CaCl_2$	trace
Water	100 cc.

[3] Ternetz, Charlotte. Ueber die Assimilation des atmosphärischen Stickstoffes durch Pilze. Jahr. f. wiss. Bot. **44**: 353–408. 1907.

[4] Other papers of interest in connection with the fixation of nitrogen by fungi are the following:

Puriewitsch, K. Ueber Stickstoffassimilation bei den Schimmelpilzen. Ber. d. deut. bot. Ges. **13**: 342–345. 1895.

Froehlich, H. Stickstoffbindung durch einige auf abgestorbenen Pflanzen häufige Hyphomyceten. Jahr f. wiss. Bot. **45**: 256–302. 1907.

Solutions. It has been the general experience that the readily culturable parasitic and hemiparasitic fungi have about the same relation to strengths of solutions as the saprophytic forms. Ordinarily, therefore, such forms give abundant growth under widely different conditions of concentration of the substratum. According to Eschenhagen the concentrations at which *Botrytis cinerea* may grow under ordinary circumstances are as follows: grape sugar, 51 per cent; cane sugar, 37 per cent; sodium nitrate and calcium chloride, 16 per cent; sodium chloride, 12 per cent. In the culture work in the laboratory it will be found, however, that differences in the strength of the culture medium will be accompanied by noticeable differences in the form of the fungous colony, amount of the mycelium, and the character of the spores produced.

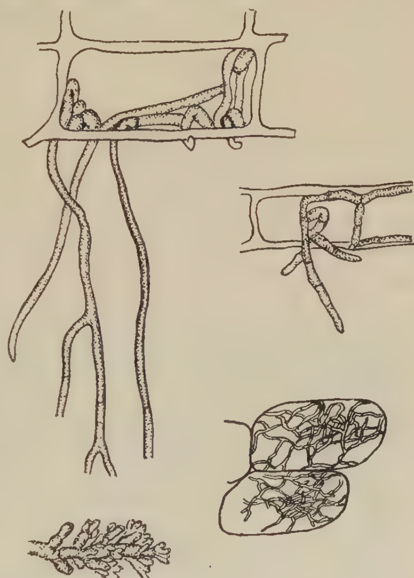


FIG. 15. CELLS OF ERICACEÆ (after Ternetz), AND ORCHIDACEÆ WITH ENDOPHYTIC MYCORHIZA, ALSO CORALLOID ROOTS

CHAPTER V

ARTIFICIAL INFECTION

Infection experiments, or, as usually termed, artificial infection experiments, are essential in pathological work. They may be undertaken for a variety of purposes, among which the most important seem to be the following:

1. To determine if a given organism is parasitic, or the cause of a particular disease.
2. To determine the conditions under which an organism is most active in producing a disease, as well as the natural seat and manner of infection.
3. To determine the range of pathogenicity of a given organism; that is, to demonstrate what varieties, species, genera, etc., may be considered, potentially at least, host plants.
4. To determine the relationship of the different stages of an organism to one another and to the host, or hosts.
5. To determine the conditions under which the different stages of a fungus may be developed.
6. To determine the special relation of a parasitic organism to lesions or abnormalities of the host, with which a parasitic organism may be constantly associated.

The rules of proof formulated by Koch, especially for disease-producing bacteria, have been repeatedly brought before investigators, yet they are too frequently ignored. They are appropriately termed the canons of Koch. They should be kept in mind in all pathological work, as they are applicable in all such studies, despite the exceptions which may sometimes be made. These rules may be expressed as follows:

a. Under diverse conditions the fungus must be constantly and abundantly associated with the disease, or pathological state.

b. The organism should be grown in pure cultures, when possible, and its differential characteristics well studied.

c. The characteristic disease should be produced by infection experiments with a pure culture.

d. The fungus associated with the disease induced should be identified as the one originally separated, and any abnormalities of host should likewise correspond.

The purposes of the infection experiments as above outlined are merely suggestive, and it is evident that a single series of experiments may give all or nearly all of the indications desired. Each subdivision, however, deserves special consideration.

1. With such obligate parasites as the Peronosporaceæ, Exoascaceæ, Erysiphaceæ, Ustilaginales, Uredinales, and some others, the

FIG. 16. CORRECT USE OF BELL GLASSES IN CERTAIN TYPES OF INFECTION WORK. (Photograph by Geo. M. Reed)

constant association of an organism with a diseased condition would usually be sufficient to denote this organism as the cause of the disease. The conditions required for spore germination are in many cases unknown, and therefore negative results would be of no great value. There is therefore a two-sided opportunity for study. It would, however, be absurd to say that *Empusa Muscæ* is not the cause of the well-known, or commonly observed, fly disease. Yet, so far as the writer is aware, no work has been done which would be counted as successful in the artificial propagation of such diseases among insects. With most groups of fungi and with the bacteria, infection experiments must be made if the work in hand

pretends to be authoritative. It is true that the great majority of fungi described as the causes of plant diseases have not undergone experimental tests, although it will be admitted by most experienced pathologists that a large proportion of the claims made are just, beyond all question. Where the spore-bearing parts of a fungus emerge directly from only slightly injured tissues, or in other equally plausible cases, the statement of parasitism made by an experienced pathologist is usually correct. In all cases where decay has set in, or where there is great discoloration of the parts affected, — especially in root and stem diseases, leaf spots, leaf burns, etc., — experiments are necessary to determine the primary cause of the disease.

It is often the case that the fruit bodies or the mycelial stages of several different fungi are found associated with a diseased condition, and it is necessary to determine either which fungus is the real cause of the trouble, or what part each one may play in the effect produced. All organisms must be isolated, and separate infection experiments should be made with each. In such cases, of course, the fungi may be only secondary, appearing more as saprophytes on plants which are diseased owing to the action of some more general environmental factor, to the injuries of some insect, or to a mechanical agent. In many instances the fruit bodies of a causal fungus may not be formed until after the death of the plant, as is particularly true of the pyrenomycetous fungi. If not readily developed in culture, for comparison with those produced in nature, it will be necessary not only to make infection experiments with the pure cultures, but also with the spores produced in the open. In general, controlled infection experiments will be more rigorously demanded as our knowledge is advanced. There are proportionally few groups of fungi which may be designated saprophytic or parasitic in more than a relative sense.

2. Infection experiments often enable one to determine the rôle which may be played in the predisposition to attack by such conditions as excessive moisture in the atmosphere or soil, the state of nutrition of the host, etc. Excessive moisture in the soil and the crowding together of seedlings offer advantageous conditions for the outbreak of damping-off diseases, produced by such fungi as Rhizoctonia and Pythium. Moisture on the leaf surfaces favors

the spread of many fungi under the more or less "forced" conditions of the greenhouses. Overhead watering or the general sprinkling of plants is sometimes alone sufficient to facilitate greatly the spread of disease, as in the case of the rust of chrysanthemums. Unusual succulence in the pear is said to be a favorable condition for infection by the pear blight organism. In general, it is believed that any conditions leading to the suffusion of the tissues of the host with water invite disease, particularly disease accompanied by the general destruction of the tissues, and finally by decay.

From extended observations Atkinson was able to say that the absence of a sufficient amount of potash in the soil predisposes the cotton plant to the attacks of *Macrosporium nigricantium*, which fungus is then the cause of a new and graver phase of the disease. Many analogous cases might be cited, all of which suggest the necessity of experimental work from the standpoint of inoculation. Recently Ward has reported that the lack, or poverty, of one or more necessary elements in the nutrition of the brome grasses does not seem to predispose those hosts to the rust fungi parasitic upon them. It may well be inquired if this is a special case, and particularly if there may be any difference in this regard between obligate and facultative parasites. In this connection, moreover, the experiments made by Salmon with *Erysiphe graminis* may be cited. He found that a wound sometimes sufficed to break down completely the immunity of certain species of grasses to a particular form, or race, of this fungus.

The method of penetration of the germ tube of the fungus can only be definitely determined by careful infection experiments. It is just as true for a fungous disease of plants as for a bacterial disease that a thorough study of the conditions has not been made until the possible methods of infection are determined. Not only is it necessary in the general etiology of the disease, but extremely important in the formulation of preventive measures. Fungi gaining entrance only through injuries or wounds are, in general, much more readily suppressed or confined.

3. Inoculation studies with certain species of Glœosporium have indicated that many distinctly disease-producing organisms may have a considerable range of host plants. A species of "Rhizoctonia" (*Corticium vagum* B. & C., var. *Solani* Burt) causing a

rot of sugar beets may cause damping-off diseases of seedlings, as well as other diseases, in several different families of hosts. Of the numerous cases which might be cited in this connection, many are in need of critical study, notably Exoascus. Among hemi-parasites, or facultative parasites, such studies will doubtless lead to a considerable reduction in the number of the so-called species of such fungi. On the other hand, infection experiments have compelled mycologists to break up among others the old species *Puccinia graminis* into several forms, frequently termed biological or physiological forms, or subspecies, which, in some cases, are entirely indistinguishable one from another on purely morphological grounds. Each form has a restricted number of host plants, and it is believed that no cross infections occur. Many similar cases have been clearly demonstrated for the Uredinales.

It has recently been shown that certain mildews, notably *Erysiphe graminis*, may likewise be broken up into forms restricted each to one or more host plants. The two fungi mentioned are instances where each parasite, as a species, is capable of infecting a large number of host plants. It remains to be seen to what extent such differentiation of forms is to be found in species more restricted as to host plants.

4. Experimental evidence was required to demonstrate the long-suspected connection between *Puccinia graminis*, the grain rust, and the common æcidium on the barberry, *Æcidium Berberidis*. Those experiments, although preceded by studies in heterœcism upon Gymnosporangium, mark a very distinct epoch in infection work, for heterœcism has proven a very important biological phenomenon. Within the past few years, particularly, much has been done towards a systematic endeavor to connect by experimental proof the heterœcious forms of Uredinales. Nevertheless, much valuable work remains to be done, and the observant student will constantly find suggestions in the proximity of host plants taken in connection with the sequence of stages in these fungi. It is well known that the occurrence of a uredo or teluto stage in connection with an æcidium, or closely following the latter, is not the final proof that these stages are connected. A close observation of many affected host plants during different seasons may, however, give some valuable clews as to relationships and prevent fruitless

experimentation. Finally, in this it is again to be urged that in a study of the relationship of stages to one another and to the host plant, by artificial infection, experiments should be made upon properly isolated hosts.

5. In some regions the production of the oospores of such fungi as *Cystopus candidus* and *Cystopus Bliti* are practically unknown; yet in other regions, and during certain seasons, the oospores are produced in great abundance. A somewhat similar fact is the continuous production of conidia by some species of Erysiphaceæ in certain habitats. Together with infection experiments under different conditions, and upon host plants of various ages, physiological studies of the host will be required.

6. It is well known that certain Uredinales and Exoascaceæ are the immediate causes of the witches' brooms of the hosts in connection with which these fungi are found. On the other hand, *Sphærotheca phytoptophila* grows only upon branches deformed by phytoptids. Fungi are associated also with many abnormalities commonly referred to as knots, cankers, etc., and in nearly all such cases infection experiments should be called into service to determine not merely if the fungus is parasitic, but also to determine if it is the primary cause of the abnormal development. Even if the fungus is known to be parasitic, from the point of view of pathology, the fungus becomes a matter of secondary importance when it is parasitic merely in consequence of some other injury or excitation.

In general, infection experiments may be carried out either in the open or in the greenhouse. Frequently it is possible to study natural infections. Nevertheless, adequate opportunities for plant pathological work have not been secured until a good greenhouse is constantly available.

The methods of making inoculations are necessarily various but always simple. With such fungi as the rusts, mildews, and many species producing leaf spots, the germ tubes usually gain entrance by boring through the epidermis or by passing in at the stomata. No injuries or abrasions of the organs inoculated being necessary, the plant may be moistened, preferably by vigorous spraying, with distilled water. Bell glasses may often be employed if ventilation is provided (Fig. 16). In some cases perfect precautions *must* be

taken to prevent the access of any spores from other sources. Ordinarily, precaution is fairly well secured by a sufficient number of control plants.

If the spores of a given fungus are obtainable in quantity, these may be sprayed on the plant with an atomizer or small pump. A small number of spores may be sponged on or applied with a camel's-hair brush. If the inoculations are made towards evening, and the plants are wrapped loosely with paper or cloth, a moist condition may be readily maintained for a period sufficiently long. The cylindrical, open-topped, glass, insect breeding-cage is extremely useful as a cover for inoculated herbaceous plants of small size (Fig. 17). The top may be closed with a cloth, and thus ventilation is well provided for, while the moisture retained is usually sufficient. It insures, also, protection against insects, but not against wind-blown spores. Tall bell glasses may be used when an atmosphere practically saturated is not objectionable. In this case, moreover, a relatively favorable state of humidity and aëration may be maintained by raising the bell glass on blocks. To provide against accidental infection great caution must be observed, as stated below. In the local inoculation of a twig, glass tubing may be slipped over the inoculated branch ; the ends of the tube may then be plugged first with moist and afterwards dry cotton. Glass vessels so employed may usually be removed within a few days.

Fig. 17. Insect Breeding-Cage in Inoculation Experiments

Bacteria and certain leaf spot and stem inhabiting fungi may require wounding of the surfaces to which they are applied. The wounds may be made either with sterile needles, scalpels, or scissors, and the depth of such wounds must be determined by experience

and specific needs. In particular work the surface thus injured should be washed, cleansed with a disinfecting solution, if the structure will permit, and again washed with distilled water before the inoculation is made. In work of this character the spores or mycelium for inoculation should be taken from a pure culture; indeed, pure cultures should always be used if the fungi are culturable, except where the only material available is hopelessly mixed, and the inoculation is only desired to eliminate some of the saprophytic forms. It is usually well to cover the wounds with grafting wax (Fig. 18), or some other similar adhesive containing no injurious substance. This will be possible in the case of stem diseases. In this case the control experiments should be wounded and covered with wax as well, so that the conditions may be quite the same. In some instances absorbent cotton may replace the wax.

Fig. 18. The Use of Grafting Wax in Inoculation Experiments

Whenever the air may too readily serve as a source of contamination, plants of large size may be fairly well protected from this source of danger by using practically air-tight glass frames, into which the air may enter only after filtration through cotton, and smaller plants may be accommodated under bell glasses with open tops loosely plugged with cotton.

Certain disease organisms gain entrance through the roots, as in the case of *Neocosmospora vasinfecta*. It will be evident in such cases that the soil should be inoculated. If possible, the plants to be inoculated should be grown in sterilized soil, but another consideration of importance frequently is to have the soil conditions imitate as closely as possible the conditions under which the disease was developed in the field; thus the type of soil and the percentage of soil moisture are important.

In all cases inoculation experiments should be made in quantity, and control experiments in similar number must be relied upon to eliminate any possibility of error. If a given disease is particularly abundant in the region, and accidental infection therefore more probable, the number of control cultures should be further increased, in addition to the special precautions mentioned.

A failure to secure infection from a relatively small number of experiments may not indicate that the particular fungus plays no part in the production of the disease with which it has been associated. At any rate, experience in pathological work is necessary when one assumes to make a positive statement in this regard. In some cases infection may occur at a definite period only, or closely related species of fungi may differ markedly with respect to the conditions under which infection may take place. It has been found that the fungus causing fruit spot of apple is effective at about the time that the hairs covering the surface of the young apple are broken off. The loose smut of oats penetrates the host only when the latter is in the seedling stage, while the smut of wheat may infect the blossom.

CHAPTER VI

THE PRINCIPLES OF DISEASE CONTROL

BAIN, S. M. The Action of Copper on Leaves with Special Reference to the Injurious Effects of Fungicides on Peach Foliage. Tenn. Agl. Exp. Sta. Bullt. (Vol.) **15**: 21–108. *pls. 1–8.* 1902.

BURT, E. A. Resistance of Plants to Parasitic Fungi. Trans. Mass. Hort. Soc. (1898): 145–161.

CLARK, J. F. On the Toxic Properties of Some Copper Compounds with Special Reference to Bordeaux Mixture. Botan. Gaz. **33**: 26–48. *figs. 1–7.* 1902.

HEDRICK, U. P. Bordeaux Injury. N. Y. Agl. Exp. Sta. Bullt. **237**: 1–189. 1907.

JACKSON, H. S. Development of Disease Resistant Varieties of Plants. Trans. Mass. Hort. Soc. (1908): 123–137.

LODEMAN, E. G. The Spraying of Plants. 399 pp. *92 figs.* 1896.

MILLARDET, A. De l'action des mélanges de sulfate de cuivre et de chaux sur le mildion. Compt. Rend. **101**: 929–932. 1885.

SCOTT, W. M. Self-Boiled Lime-Sulphur Mixture as a Promising Fungicide. Bureau Plant Industry, U. S. Dept. Agl. Circular **1**: 1–18. *figs. 1, 2.*

(Spray Calendars and Bulletins of the Agl. Exp. Sta.'s in the United States.)

SWINGLE, W. T. Bordeaux Mixture. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **9**: 1–37. 1896.

I. METHODS OF CONTROL

A proper knowledge of the life histories of parasitic fungi, experience in the use of spray mixtures, an adequate conception of crop requirements, and a comprehension of general plant physiology make possible in the great majority of cases a rational means of disease control.

Eradication, prevention, or control of fungous diseases may be brought about more or less successfully by proper regard for such factors as varietal resistance, seed selection, crop rotation, seed treatment, application of fungicides to the growing crop, and general sanitation. It is frequently necessary to combine several methods of procedure in combating the attacks of a single organism, and in no case should practices of general sanitation be disregarded.

Resistant varieties. Notable instances of the resistance of particular varieties of important parasitic fungi have been brought to

the attention of growers and pathologists from early times. It is, in fact, seldom that all the individuals of even a well-established variety are equally susceptible to disease, and the differences between closely related varieties are often surprisingly great. The Iron cowpea has been shown to be far more resistant than other varieties to the wilt disease, and a new strain of cotton, the Dillon, possesses similar qualities with respect to the same fungus. Every carnation grower became familiar a few years ago with the fact that the Scott carnation was peculiarly susceptible to carnation rust, and that under ordinary conditions the Enchantress was peculiarly resistant. The Kieffer pear is far less attacked by blight and leaf spot fungi than other varieties commonly grown. Nearly all fruits, vegetables, field crops, and floricultural plants will, upon careful investigation, give evidence of more or less striking qualities of resistance. This resistance may be inherited, or it may be a characteristic which changes markedly as the climatic or soil conditions vary under which the host plant may be growing. The relations to disease may, therefore, be complex, and it is not the purpose of this summary account of disease control to describe at length the diverse relations of host and parasite.

Seed selection. Seed selection is, in many cases, the easiest and most natural method of disease control. The anthracnose of beans is carried over from crop to crop very largely by means of diseased seed, and it has been shown that diseased pods mean as a rule diseased seed, that treatment of such diseased seed is not effective, and that, therefore, the most rational method of combating the organism is to plant seed from selected pods. It is very probable that the anthracnose of cotton is similarly transferred from year to year. Certainly the appearance of the anthracnose abundantly upon the seedlings, especially upon the cotton leaves, suggests the presence of the organism in the seed. The late blight of potato seems to be commonly, if not entirely, carried over from season to season by means of diseased tubers, the latter being infected with a form of the disease known as the potato rot. The selection of seed from a field in which no blight has been present to a very large extent insures a crop free from blight. Seed selection is already practiced to a considerable extent, but there is no line of disease control requiring more attention at the present time.

Crop rotation. There is no small number of fungous diseases which reappear year after year on account of the fact that the soil has become contaminated with the spores or mycelium of the fungus, these stages being often able to remain alive throughout a considerable period of time. It is only possible to prevent many of these diseases by the practice of a suitable rotation. Land infested with the organism causing club root of cabbage and turnips should be kept free from cruciferous plants for two years. The fungus producing scab of potatoes is far more persistent in the soil than the last mentioned; and *Urocystis Cepulæ*, the onion-smut organism, is supposedly able to retain the capacity for germination in the soil for a number of years. In addition, there are many other fungous, as well as bacterial, diseases for which it is essential to practice the strictest rotation principles.

The application of fungicides. The application of fungicides to the growing crop has been for about twenty years a principal means of disease control or prevention. In this connection it is understood that the application of a fungicide to the host plant is generally for the purpose of protecting it from an attack of a fungus. In only a few cases is it possible to actually kill an organism which is already causing injury. In the case of some of the powdery mildews the use of any fungicidal sprays or dusts may be beneficial, in part, from the direct killing action of the fungicide upon the superficial growth of the fungus. In the great majority of instances the fungicide is applied with the view of covering a healthy plant, which is thus to be kept in healthy condition. The germination of the fungous spore, which may follow upon the host subsequent to the application of the fungicide, should thus be prevented. It has been fairly well demonstrated that the germinating spore will, for instance, absorb from the nearly insoluble copper compounds of Bordeaux mixture sufficient toxic substances to cause its death.

At the same time, it is, of course, necessary that the fungicides shall be of a nature and strength which will be in general noninjurious to the plant which is to be protected. It is not, however, possible to determine this point precisely, since apparently under different climatic conditions the injurious action of the fungicide may vary greatly. Weak Bordeaux mixture will be noninjurious to the foliage of peach and plum, or even to apple, one season and

the following year applied with equal care the same mixture will cause great injury or defoliation. Moreover, since the various parasitic fungi are differently affected by the strength as well as the composition of the fungicide, it is important to know the specific relations of each important parasitic organism. In the use of fungicides there is a very large field of investigation possible because of the fact that an intimate knowledge of the life histories of the organisms concerned alone affords a proper index of the best time for the application of the mixture, climatic conditions, and innumerable other factors, serving also to modify the requirements in special cases. It has been possible to control very satisfactorily the blight fungi of potato, most of the commoner grape parasites, the bitter rot and scab of the apple, as well as numerous other diseases by proper use of Bordeaux mixture. Nevertheless, Bordeaux mixture should not be relied upon to the exclusion of other fungicides, nor is the indiscriminate use of any fungicide to be generally recommended.

II. PREPARATION OF FUNGICIDES

The more commonly employed of the many fungicides, which have been used by practical growers and plant pathologists, are as follows: Bordeaux mixture, ammoniacal copper carbonate, lime-sulfur wash, potassium sulfide, flowers of sulfur, copper sulfate, corrosive sublimate, and formalin. Of these preparations the first five may be employed upon the foliage during the growing condition of the plants. The remaining substances are generally used for disinfection of seeds and plants in dormant or winter condition.

Bordeaux mixture. Bordeaux mixture is the most important and the most commonly employed of fungicides. As a rule it is true that Bordeaux mixture will protect a plant from fungous attack where it is possible to protect it by means of any spray mixture. Its injurious effects upon some plants preclude its use. In other cases the discoloration of fruits immediately before marketing would render them less desirable for market purposes, and again the discoloration of the foliage makes it objectionable in the case of ornamental plants. Bordeaux mixture may be used also for plants in dormant condition. Under such circumstances

very strong solutions may be employed. The strength of solution now generally regarded as a standard consists of:

Copper sulfate	5 lb.
Stone lime	5 lb.
Water	50 gal.

A mixture of this strength is known as the 5–5–50 formula. The strength may be decreased or increased as desired, and it will be expressed in a similar manner, thus 2–2–50 and 10–10–50 respectively refer to 2 pounds of each chemical and to 10 pounds of each in 50 gallons of water. The method of making Bordeaux consists in dissolving the required amount of copper sulfate in an equal number of gallons of water, the copper sulfate being placed in a sack and suspended in a barrel or other vessel, this method greatly facilitating the solution.

The amount of lime required may be slowly slaked in another barrel or vessel and then brought up to a thick milk with a known quantity of water. This solution may be used as a stock solution, 1 gallon of the copper sulfate representing 1 pound of the copper salt, and 1 gallon of the lime milk representing 1 pound or more according as the mixture has been prepared. The amount of the copper solution for a barrel or tank may then be diluted practically to the capacity of the vessel employed, and then the fairly diluted lime milk is poured in, stirring constantly. It is desirable that the latter should be strained. The strong stock solutions should not be poured together.

Ammoniacal copper carbonate. This preparation is frequently employed where a strong fungicide is needed, and where the color of the Bordeaux mixture renders it objectionable, the ammoniacal solution discoloring foliage to only a very slight extent. The constituents of this mixture are as follows:

Copper carbonate	5 oz.
Ammonia (26° Baumé)	3 pt.
Water	50 gal.

The strong ammonia, which one must handle carefully, may be diluted to about five times its volume, and the copper carbonate may be rubbed up with water in a small vessel to form a thin paste. This paste is added to the now dilute ammonia with

constant stirring. The mixture is then brought up to 50 gallons. Ammoniacal copper carbonate should be used as promptly as possible, owing to the rapid evaporation of the ammonia.

Lime-sulfur wash. The lime-sulfur preparation which may be employed with least fear of injury to growing plants is a form known as "self-cooked." It has been introduced relatively recently, and, therefore, has not been extensively employed by commercial growers. The constituents are as follows:

Flowers of sulfur	10 lb.
Stone lime	10 lb.
Water	50 gal.

The preparation of the mixture is simple. After weighing the lime into a barrel add three gallons of water, sift in the sulfur, and slake the lime slowly. As heating proceeds add more water and stir occasionally. The heat developed is sufficient to "cook" to the extent desired. When completely slaked cool promptly by diluting to fifty gallons. Patent preparations are made.

Potassium sulfide. Potassium sulfide is a fungicide which is also employed when it is undesirable to have foliage discolored. It is, moreover, believed to be especially effective in the prevention of certain mildews, especially that of the gooseberry, and also the rust of carnations. This substance is sometimes known as liver of sulfur, and should, when fresh, make a solution yellowish brown. It is employed in the following preparation:

Potassium sulfide	3–5 oz.
Water	10 gal.

Sulfur. Flowers of sulfur is often surprisingly effective in the treatment of certain surface mildews, such as that of the rose. It may be dusted over the plants so as to fairly cover them with the yellow powder, and is particularly effective when the plants are wet. A paste of sulfur and lime is also employed by many growers in rose houses, the method of application being then to smear the steam pipes with the mixture, the fumes from which are disastrous to the mildew.

Recently a sulfuric acid solution of a strength of 1–1000 has also been successfully employed in the treatment of rose mildew and similar fungi.

Copper sulfate. Copper sulfate is frequently employed as a wash for dormant trees and also for disinfecting seed of grains which may be contaminated by adherent fungous spores. The solution may be prepared as suggested under Bordeaux mixture. When diluted, it should consist of:

Copper sulfate	1 lb.
Water	15 gal.

It is seldom that one would desire to apply copper sulfate to the growing tree, on account of its injurious action upon the leaves, but occasionally it has been employed at a strength of 1 pound to 100 gallons of water.

Corrosive sublimate. Bichloride of mercury, commonly known as corrosive sublimate, is an unusually strong poison for man as well as for animals; at the same time it is a very effective disinfectant and is very generally employed for potato scab. The solution consists of:

Corrosive sublimate	2 oz.
Water	15 gal.

This is practically a solution of 1–1000 by weight, a strength commonly employed by physicians for disinfecting purposes. Seed potatoes which may have come in contact with the scab fungus should be soaked for one and a half hours in a solution of the strength indicated. This solution may also be used as an antiseptic dressing for wounds, especially after pruning. It should be made in a wooden or earthenware vessel, since it attacks metallic substances vigorously.

Formalin. Formaldehyde vapor dissolved in water to give a solution which is ordinarily 40 per cent bears generally the commercial name formalin. It is like the last-mentioned fungicide, also a strong disinfectant, and is used very extensively for treating seed potatoes and seed oats and wheat. It should be employed of the following strength:

Formalin	1 oz.
Water	2 gal.

Since formalin is a chemical which may be handled more conveniently and with less danger than corrosive sublimate, it must be given the preference.

Precautionary measures. Among the fungicides discussed arsenical poisons have not been included for the reason that they are supposed to be of importance only in the control of insect pests. Frequently it becomes desirable to combine an arsenical compound — Paris green, for instance — with Bordeaux mixture, and thus accomplish a double purpose. In that case more than a pound of lime, additional, should be included in the Bordeaux for each pound of the Paris green employed, otherwise injury may result.

The lime-sulfur mixtures are now receiving attention throughout the country, and there are indications that they may become important. Experiments thus far show that the ordinary lime-sulfur wash is much more toxic to sensitive foliage than the "self cooked." Growers should therefore clearly distinguish between these preparations. Moreover, the ordinary lime-sulfur is a kind of whitewash, and if employed when the fruit is approaching maturity, it may be objectionable in marketing.

PART III

FUNGOUS DISEASES OF PLANTS

CHAPTER VII

GENERAL CLASSIFICATION

I. FUNGOUS DISEASES AND PATHOLOGY

COMES, D. O. Crittogamia agraria. 600 pp. *17 pls.* 1891.
FRANK, A. B. Die Krankheiten der Pflanzen (Pilzparasitären Krankheiten) **2**: 574 pp. *95 figs.* 1896. Breslau.
FREEMAN, E. M. Minnesota Plant Diseases (Report of the Survey, Bot. Series V). 432 pp. *211 figs.* 1905. St. Paul.
HARTIG, R. Lehrbuch der Baumkrankheiten. 3d ed. 324 pp. *250 figs.* 1900. Berlin. (2d ed. transl. into English by Somerville and Marshall Ward. 331 pp. *159 figs.* 1894.)
KÜHN, J. Krankheiten der Kulturgewächse. 312 pp. *7 pls.* 1858. Berlin.
MASSEE, G. Text-book of Plant Diseases. 458 pp. *92 figs.* 1896.
PRILLIEUX, ED. Maladies des plantes agricoles et des arbres fruitiers et forestiers causées par des parasites végétaux **1**: 421 pp. *190 figs.*; **2**: 592 pp. *figs. 191–484.*
SMITH, W. G. Diseases of Field and Garden Crops. 353 pp. *143 figs.* 1884.
SORAUER, P. Pflanzenkrankheiten **2**: (2d ed.) 456 pp. *18 pls. 21 figs.* 1889. Berlin. (3d ed. revised by Lindau. 562 pp. *62 figs.* 1908.)
TUBEUF, K. VON, and SMITH, W. G. Diseases of Plants induced by Cryptogamic Parasites. 598 pp. *330 figs.* 1897.
UNGER, F. Die Exantheme der Pflanzen und einige mit diesen verwandte Krankheiten der Gewächse. 422 pp. *7 pls.* 1833.
WARD, H. MARSHALL. Timber and Some of its Diseases. 295 pp. *45 figs.* 1889.
WARD, H. MARSHALL. Diseases in Plants. 309 pp. 1901.

If we interpret disease as any apparently abnormal condition of an organism or of its parts or functions, it is evident that the diseases of plants, like those of other living things, include morphological and physiological disturbances which may be induced by a variety of environmental factors, living or nonliving. The popular conception excludes from the category of plant diseases those effects caused by predatory animals or by sudden mechanical

means. There is also a tendency to dissociate from plant diseases proper the widespread devastation which is the result of the varied injuries annually inflicted by insects. In general, therefore, we may disregard insects as the cause of plant diseases when that term is applied narrowly.

It is within comparatively recent times that the specific injuries or modifications of climatic or other physical factors of the environment have been carefully studied. When properly understood, these effects have moreover frequently been termed "physiological" as opposed to "pathological." With a broad definition of pathological this interpretation would be illogical. Nevertheless the student of fungous diseases of plants has been the chief plant pathologist. This is partially due to the fact that the disease-producing fungi are intimately associated with the structure of plants, and a proper study of the fungus has necessitated a thorough comprehension of its relation to the plant upon which it grows, the host. Plant diseases and plant pathology are, therefore, more or less synonymous with fungous diseases of plants, and the narrow use of the term *plant pathology* will on this account doubtless long persist.

II. THE CLASSES OF FUNGI

Corda, A. C. I. Icones Fungorum. (In 6 parts, large 4to.) 366 pp. *64 pls.* 1837–1857.

Ellis, J. B., and Everhart, B. M. North American Pyrenomycetes. 793 pp. *31 pls.* 1892.

Engler and Prantl (Eds.). Die natürlichen Pflanzenfamilien **1** (1*): 570 pp. *263 figs.;* **1** (1**): 513 pp. *293 figs.*

Farlow, W. G., and Seymour, A. B. A Provisional Host Index of the Fungi of the United States. 219 pp. 1888–1891.

Saccardo, P. Sylloge Fungorum. (18 vols. to date.) 1882–1906.

Schroeter, J. Die Pilze (Cohn's Kryptogamen Flora von Schlesien), Pt. **1**: 814 pp.; Pt. **2**: 500 pp. 1869.

Winter, G. Die Pilze (Rabenhorst's Kryptogamen Flora), Vol. **1** (Pt. 1): 924 pp. Ill.; Vol. **1** (Pt. 2): 928 pp. Ill.

Brefeld, O. Untersuchungen aus dem Gesammtgebiete der Mykologie. (Extensive; in 13 parts; illustrated.) 1872–1905.

Cooke, M. C. Introduction to the Study of the Fungi. 360 pp. *148 figs.* 1895.

De Bary, A. (Transl. into English by Garnsey and Balfour.) Comparative Morphology and Biology of the Fungi, Mycetozoa, and Bacteria. 525 pp. *198 figs.* 1887.

Lafar, Fr. (Ed.). Handbuch der technischen Mykologie. (In 5 vols.; 4 vols. complete to date.) **1**: 749 pp. *2 pls. 95 figs.;* **2**: 503 pp. *10 pls. 90 figs.;* **3**: 573 pp. *37 figs.;* **4**: 558 pp. *122 figs.* 1904– .

TAVEL, F. VON. Vergleichende Morphologie der Pilze. 208 pp. *90 figs.* 1892.
TULASNE, L. R. et C. Selecta Fungorum Carpologia. (In 3 vols.) 782 pp. *64 pls.* 1861–1865.
UNDERWOOD, L. M. Molds, Mildews, and Mushrooms. 214 pp. *9 pls.* 1899.
ZOPF, W. Die Pilze. 500 pp. *163 figs.* 1898.

Every great division, or class, of the fungi contains some species capable of producing disease in other plants. Disease, in this connection, refers to a physiological disturbance, often accompanied by anatomical injuries or hypertrophies. The number of such disease-producing organisms is sometimes very limited in a class, and there are orders in which no such organisms have been described.

In a restricted sense the fungi may include only certain classes of chlorophyll-free thallophytes, but in the broader application of the term, it includes all chlorophyll-free organisms which may be regarded as plants. It is with this latter meaning that the term is here used, in so far as the general selection and arrangement of material is concerned, although this will not be permitted to affect the use of the word in a restricted sense as well. The fungi include five well-marked classes of organisms, as follows:

1. *Myxomycetes.* The slime molds.
2. *Schizomycetes.* The bacteria.
3. *Phycomycetes.* Water molds, black molds, downy mildews, etc., — algal-like fungi.
4. *Ascomycetes.* The ascus-bearing fungi.
5. *Basidiomycetes.* Basidia-bearing fungi, — smuts, rusts, mushrooms, etc.

This grouping, however, shall not be taken to indicate a line of development beginning with the slime molds and advancing through the other groups to the smut and mushroom class. In fact, only the Phycomycetes, Ascomycetes, and Basidiomycetes, which have much in common, may be regarded as the true fungi, and nearly all the species here included have a filamentous vegetative stage. The bacteria form a coherent, distinct class, yet certain families show very close relationship with the fungi, while others show more striking resemblances to certain families of algæ. The bacteria have, moreover, in no sense any very close animal-like allies. The Myxomycetes have no very apparent relationship with any other

groups of fungi or algæ; although in the lowest Phycomycetes, perhaps, one may find a certain questionable similarity. However, it would seem that the closest allies of the Myxomycetes, as possibly of some of the lowest Phycomycetes, may be with the Flagellates. Finally the Myxomycetes resemble also in some characters other animal-like groups, such as the Sporozoa and the Myxosporidia. It is, however, unnecessary here to enter into a special discussion of the relationship or homologies of any of these organisms.

CHAPTER VIII

MYXOMYCETES. SLIME MOLDS

I. PHYTOMYXALES (PHYTOMYXACEÆ)

In the family Phytomyxaceæ are grouped the few disease-producing organisms among the Myxomycetes. The family is characterized by the production of naked masses of protoplasm (plasmodia) within the cells of the host. The plasmodium gives rise simultaneously, or by a successive differentiation, to sphæroidal spores, and the germination of the spore produces a motile swarm cell, by means of which distribution of the organism is effected. Generic differences are found almost wholly in the relation of the spores one to another, whether single or grouped. *Plasmodiophora Brassicæ* is the only well-known species of economic importance.

II. CLUB ROOT OF CABBAGE AND OTHER CRUCIFERS

Plasmodiophora Brassicæ Wor.

EYCLESHYMER, A. C. Club-root in the United States. Journ. Myc. **7**: 79–87. *pls. 15–16.* 1892.

HALSTED, B. D. Club-root of Cabbage and its Allies. N. J. Agl. Exp. Sta. Bullt. **98**: 1–16. *figs. 1–13.* 1893.

NAWASCHIN, S. Beobachtungen über den feineren Bau. u. Umwandlungen von Plasmodiophora. Flora **86**: 404–427. *pl. 20.* 1899.

WORONIN, M. Plasmodiophora Brassicæ. Jahrb. f. wiss. Bot. **11**: 548–574. *pls. 19–24.* 1878.

The club root, or club foot, is an unsightly and destructive root disease of crucifers which has been known in Europe for considerably more than a century. In England it is commonly called fingers and toes, anbury, etc. (Germany, Kohlhernie; France, maladie digitoire). Our knowledge of the causal relations of a Myxomycete, Plasmodiophora, to the disease is primarily based upon the excellent researches of Woronin published in 1878.

Habitat relations. In Europe the fungus is quite generally distributed throughout the market-gardening sections. In 1876

Woronin estimated the losses due to it in the vicinity of St. Petersburg at $225,000. In the United States it has been disastrous in many of the northeastern states, particularly in those trucking regions which supply the markets of New York and Boston.

FIG. 19. CLUB ROOT OF CABBAGE, PRODUCED BY *PLASMODIOPHORA BRASSICÆ* WOR.

It is, however, occasionally found both South and West. The limits of its distribution have not been clearly defined. Unquestionably it thrives best in a rich, warm, moisture-retaining soil.

Seedling plants affected by this parasite show a decided "flagging." They are stunted, unhealthy in appearance, and they may gradually die. Few of those affected when young reach maturity. The parasite attacks the roots and gains entrance to the parenchymatous tissues. The presence of the organism within the cells affords a stimulus to abnormal growth. There results, in fact, malformities of striking appearance. These vary, on the one hand, from slight nodose swellings in the small rootlets, and knotty masses in the tough roots of some weeds, to the more or less irregular, but generally fusiform, digitate swellings (Fig. 19) in the cabbage, and the lobulated enlargements of the turnip.

Many members of the mustard family, Cruciferæ, are subject to the attacks of this fungus. A complete list of the hosts upon which it has been found cannot be given on account of the fact that much information has been covered up by too general statements. In the United States, however, it certainly occurs upon

varieties of cabbage, cauliflower and Brussels sprouts (*Brassica oleracea*), turnip (*Brassica campestris*), rutabaga (*Brassica Rapa*), radishes (*Raphanus sativa*), and certain mustards (Sinapis and Brassica). It has also been found upon such weeds as shepherd's purse (*Capsella Bursa-pastoris*) and hedge mustard (*Sisymbrium officinale*). In Europe besides most of the plants mentioned *Mathi-*

FIG. 20. A CROSS SECTION OF CABBAGE ROOT AFFECTED BY THE CLUB ROOT FUNGUS. (Invaded cells enlarged and phloem tissue multiplied)

ola incana and *Iberis umbellata* are hosts. There seems to be little recent data of interest bearing upon the comparative susceptibility of different varieties of cultivated plants. Many mistakes have doubtless been made in assigning to this fungus injuries appearing upon other orders of host plants, and sometimes even those upon crucifers, due to nematode worms. It is often difficult to distinguish between the two causes of disease.

Morphology. Fungus and deformity. The parasite is supposed to gain entrance to the host plant during the swarmspore stage, or immediately upon leaving the swarmspore stage, therefore in the amœboidal form. No observations, however, have been made relative to host penetration, and the subject would doubtless prove an interesting one.

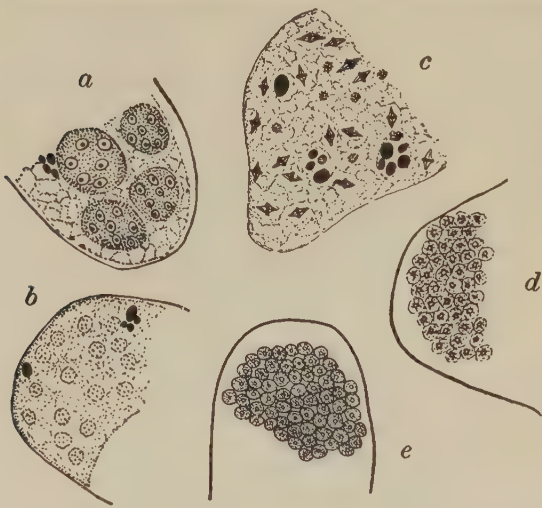


FIG. 21. STAGES IN THE DIFFERENTIATION OF THE PLASMODIUM AND SPORES IN *PLASMODIOPHORA BRASSICÆ* (After Nawaschin)

A microscopic study of sections of the diseased root shows that the organism is most abundant in parenchymatous cells, often in the vicinity of the cambium. There is in quantity an abnormal development of phloem. The xylem portions of affected roots are relatively inconspicuous. According to some observers, certain bundle elements may also show the parasite.

The infested cells are ordinarily in groups (Fig. 20) and Nawaschin believes that these groups originate by the division of a single cell and that such groups may also transmit an influence to similar tissues even at a distance, so that there may eventually result, for instance, histological disturbances in neighboring bundles. It is possible, however, that the young cells of the bundles may become infected and that the organism may be enabled to maintain itself in such cells for a time after differentiation of the latter as distinctive bundle elements.

In an earlier stage the contents of the infected cells is of a half-fluid consistency, later turbid, and finally granular. Even in the first stage the parasite is noticeable in the amœboidal form and

the nuclei may be distinct (Fig. 21, *a*). The number of amœbæ is increased by division, probably by a kind of budding process. Starch is present in the host cells but the amœba gives only a reaction for oil. No migration of the amœboidal stage from cell to cell has been observed. Several nuclei are present in each amœba, and as the number of the latter is increased they become rounded and pressed closely together into what is practically a plasmodium. The spore-forming stage is then initiated, accompanied first by peculiarities in the nuclei, which seem to disappear more or less, according to Nawaschin; and this stage is followed, upon again clearly distinguishing the nuclei, by a new form of nuclear division, mitotic and simultaneous in all nuclei (Fig. 21, *b* and *c*). There may be successive simultaneous divisions, and then the spores are differentiated by the formation of a cell wall around each nucleus and surrounding cytoplasm. Two stages in the differentiation of the spores are shown in Fig. 21, *d* and *e*.

Olive [1] and Jahn [2] have recently described what seems to be a sexual process in certain Myxomycetes (notably in Ceratiomyxa). It remains to be seen how these observations will finally be interpreted, and further, if there may also be fusion of the nuclei in the case of Plasmodiophora. In this connection it may be stated, however, that some mycologists doubt the relationship of Plasmodiophora with the Myxomycetes.

At maturity most of the pathological cells are packed full of the spherical thick-walled spores, and the latter are perhaps set free only by the disintegration of the roots. Certain unusual appearances, moreover, have been described, but these are not understood. In from four to twenty-four hours the spores will germinate in water in which some of the host tissue has been teased out, the contents of each spore escaping in the form of an irregular protoplasmic mass which may quickly change its form. There is at first, for the most part, an appearance of an elongated process or cilium, which doubtless permits rapid motility, denoting also a swarmspore stage. In the swarmspore stage a nucleus and

[1] Olive, E. W. Cytological Studies on Ceratiomyxa. Trans. Wis. Acad. Sci., Arts and Letters **15** (2): 753–774. 1907.

[2] Jahn, E. Myxomycetenstudien, VI Kernverschmelzungen. . . . Ber. d. Deut. Bot. Ges. **25**: 23–26. 1907.

a pulsating vacuole are always seen. Fig. 22 shows a spore and some swarmspore stages. Later, the protoplasmic mass moves wholly by amœboidal streaming. It is believed that the swarmspores may fuse into small amœboidal plasmodia and that these may also gain entrance to the host. Nevertheless, the true plasmodial stage is apparently that which is developed immediately preceding spore formation. It has been noted that in the same cell the development of the spores is simultaneous, and this may be true also of a whole cell group (Krankheitsherde) occupying an area so large as to be visible to the unaided eye. So it would seem probable that we may look upon a plasmodium as extending through a considerable mass of tissue. The mature spore possesses a refractive wall, or membrane, the contents are granular, and include some differentiated bodies, or globules, the nature of which has not been carefully determined.

FIG. 22. *PLASMODIOPHORA BRASSICÆ:* SPORE, GERMINATING SPORE, AND SWARMSPORES

Control. On account of the fact that this parasite gains entrance through the soil, numerous experiments have been made in the treatment of soils with lime, sulfur, and other fungicidal substances. In general it has been found that liming is the most reliable method of prevention, lime being applied to ordinary soils at the rate of about one hundred bushels per acre every few years. It is further very important that all refuse from a previous crop should be destroyed. It is especially advisable that such refuse should not be thrown upon the compost heaps. Rotation of crops, with destruction of weeds which may harbor the parasite, should also receive attention.

CHAPTER IX

SCHIZOMYCETES. BACTERIA

CHESTER, F. D. A Manual of Determinative Bacteriology. 401 pp. *190 figs.*
MIGULA, W. System der Bakterien **1**: 368 pp. *6 pls.* 1897; **2**: 1069 pp. *18 pls.* 1900.
SMITH, ERW. F. Bacteria in Relation to Plant Diseases. Carnegie Inst. of Washington, Publication **27** (Vol. I): 285 pp. *31 pls. 145 figs.* 1905.
VAN HALL, J. J. Bijdragen tot de kennis der Bakterieele Plantenziekten. 197 pp. 1902. Amsterdam.

The Schizomycetes, or fission fungi, better known as the bacteria, embrace numberless species of microörganisms which are, perhaps, morphologically the simplest of the fungi. These organisms consist of minute single cells, and while the cells may often be arranged in chains or filaments, loosely associated in colonies, or temporarily bound together in sheaths, there is no case in which an individual may be looked upon as more than a single cell. The cell forms of these organisms may be constantly assigned to one of only three general types, namely, spherical (Coccus type), rod-like (Bacillus type, varying from spheroidal to long rod-shape), and spiral (Spirillum type or screw form). The diameter of the cells of the coccus forms may vary from .3 to 3 μ (micromillimeters), and of other forms from .3–4 × 1–20 μ, the maximum being attained by the screw form. These organisms play an exceedingly important rôle in the economy of nature. The great majority are saprophytic, yet many species induce diseases of animals. A relatively small number of species included in a single family (so far as present knowledge goes) produce diseases in plants. These diseases, however, rank among the most important both on account of the destructive action of these organisms and the great difficulty experienced in attempting to develop effective means of control. The number of phytopathological forms is annually augmented, and it is probable that they will be reckoned as relatively more important as further investigations are made.

Owing to the simple forms of these organisms, a thorough knowledge of the morphology of a species would not alone suffice, even roughly, to differentiate the numberless more or less similar species. Fortunately, the development of pure-culture methods has made possible a variety of tests, or points of comparison. Growth characteristics of colonies, the reactions and products on numerous culture media, the thermal, photal, pathological, and other relations of the germ — in short, all physiological properties — must be studied and tabulated in order to make accurate and trustworthy comparisons.

Recently a descriptive chart has been prepared for the Society of American Bacteriologists [1] which indicates concisely, yet completely, the characters which should be carefully studied and tabulated in the case of any organism before it may be said that the organism may be fully and properly described. This chart should be in the hands of every student and would serve as a score card. In short, the description covers general morphology, cultural features, certain physical and biochemical characteristics, and pathogenic relations. Under morphology, size, form, and adherence of the vegetative cells are noted. The nature of the movement, the type of endospores, flagella, capsules, zooglœa, involution forms, and staining reactions should be followed. The cultural features include a complete discussion of agar, streak and stab cultures, and also cultures on potato, blood serum, gelatin; beef broth, milk or litmus milk, starch jelly, silicate jelly, a special study of the colonies on agar and gelatin, and the special growth reactions upon synthesized nutrient solutions.

The physico-chemical features are concerned with the production of gases, acids, alkalis, alcohol, ferments, etc.; the reduction of nitrates, or the presence of nitrites or nitrates in the culture; indol-production, resistance toward acids, alkalis and other toxic agents; vitality; and temperature relations, particularly the thermal death point, the maximum, minimum, and optimum for growth.

In the case of the pathogenic organisms, a complete study of infection, the relation of the organism to the legions produced, and special reaction of hosts and parasite should be considered.

[1] This chart was prepared by F. D. Chester, F. T. Gorham, and Erwin F. Smith, and was indorsed by the Society at its annual meeting, December 31, 1907.

This is accompanied by a numerical system for recording the salient characters of an organism, as follows:

100.	Endospores produced
200.	Endospores not produced
10.	Aërobic (strict)
20.	Facultative anaërobic
30.	Anaërobic (strict)
1.	Gelatin liquefied
2.	Gelatin not liquefied
0.1	Acid and gas from dextrose
0.2	Acid without gas from dextrose
0.3	No acid from dextrose
0.4	No growth with dextrose
.01	Acid and gas from lactose
.02	Acid without gas from lactose
.03	No acid from lactose
.04	No growth with lactose
.001	Acid and gas from saccharose
.002	Acid without gas from saccharose
.003	No acid from saccharose
.004	No growth with saccharose
.0001	Nitrates reduced with evolution of gas
.0002	Nitrates not reduced
.0003	Nitrates reduced without gas formation
.00001	Fluorescent
.00002	Violet chromogens
.00003	Blue chromogens
.00004	Green chromogens
.00005	Yellow chromogens
.00006	Orange chromogens
.00007	Red chromogens
.00008	Brown chromogens
.00009	Pink chromogens
.00000	Non-chromogenic
.000001	Diastasic action on potato starch (strong)
.000002	Diastasic action on potato starch (feeble)
.000003	Diastasic action on potato starch (absent)
.0000001	Acid and gas from glycerin
.0000002	Acid without gas from glycerin
.0000003	No acid from glycerin
.0000004	No growth with glycerin

(*Pseudomonas campestris* (Pam.) Erw. Smith becomes Ps. 211.333151.)

The bacteria are ordinarily grouped in six families, arranged in two orders, but the phytopathological forms are included in the one family Bacteriaceæ.

I. BACTERIACEÆ

These organisms consist of cylindrical or occasionally somewhat ovoidal rod-like cells, straight or very slightly curved, never spiral. Growth is by elongation of the rod, and division takes place by a septum (leading to a fission) perpendicular to the direction of elongation. Separation of the daughter cells may take place in such a way that the cells may commonly be single, or united two or more in a chain. Endospores are frequent, rare, or wanting, depending upon the species. Motile organs (flagella) may or may not be present.

The majority of the important plant disease-producing species thus far found are included in two genera, both of which possess motile organs,[1] viz. Pseudomonas[2] and Bacillus.

Pseudomonas Migula. These organisms are motile by means of flagella on one pole of the cell only, the flagella varying in number from 1 to 10, usually 1–3 (monotrichiate or lophotrichiate). Endospore formation is relatively rare.

This is a rather comprehensive genus on account of the variability in the number of flagella, varying on the one hand towards Bacillus, and on the other, when the rods are slightly curved, toward Microspira of the spiral forms. Among species of special interest in this connection are the following: *Pseudomonas campestris* (Pammel) Erw. Smith, *Pseudomonas Stewarti* Erw. Smith, *Pseudomonas Phaseoli* Erw. Smith, *Pseudomonas tumefaciens* (Erw. Smith and Townsend). *Pseudomonas Oleæ* (Arcan.) Trev., *Pseudomonas Hyacinthi* (Wakker) Erw. Smith, *Pseudomonas vascularum* (Cobb) Erw. Smith, *Pseudomonas Juglandis* Pierce, *Pseudomonas malvacearum* Erw. Smith, *Pseudomonas Syringæ* van Hall, and *Pseudomonas Pruni* Erw. Smith may also be mentioned.

Bacillus Cohn (emend.). These organisms are motile by means of wavy-bent flagella scattered irregularly over the cell (polytrichiate).

[1] A few species of the nonmotile genus Bacterium (Migula emend.) have been described as of phytopathological interest, among which are *Bacterium teutlium* Metcalf. (Centrbl. f. Bakt. Parasit. u. Infektionskr. **13** (II. Abt.): 28–30. 1904; also Neb. Agl. Exp. Sta. Rept. **17**: 69–112. 1904.)

[2] Smith has advanced (Bacteria in Relation to Plant Diseases, pp. 168–171) strong arguments for the substitution of Bacterium in place of Pseudomonas; and he would establish a new generic name, Aplanobacter, for the nonmotile forms generally referred to Bacterium.

The flagella in many species are relatively evanescent, or produced at a definite period, so that the time of motility may be brief. The cells are more commonly united into short threads than in the case of the preceding genus. Endospores are frequent. Among the species of much importance may be mentioned the following: *Bacillus amylovorus* Burrill, *Bacillus tracheiphilus* Erw. Smith, *Bacillus carotovorus* Jones, *Bacillus aroideæ* Townsend, *Bacillus solanacearum* Erw. Smith, *Bacillus Hyacinthi-septicus* Heinz, *Bacillus Cubonianus* Macch.

II. BLACK ROT OF CABBAGE

Pseudomonas campestris (Pammel) Erw. Smith

GARMAN, H. A Bacterial Disease of Cabbage. Ky. Agl. Exp. Sta. Rept. **3**: 43–46. 1890.

HARDING, H. A. Die schwarze Faulnis des Kohls und verwandter Pflanzen, eine in Europa weit verbreitete Pflanzenkrankheit. Centrbl. f. Bakt. Par-ask., u. Infektkr. **6** (II. Abt.): 305–313. 1900.

HARDING, STEWART, PRUCHA. Vitality of the Cabbage Black Rot Germ on Cabbage Seed. N. Y. Agl. Exp. Sta. Bullt. **251**: 177–194. 1904.

PAMMEL, L. H. Bacteriosis of Rutabaga (*Bacillus campestris* n. sp.). Iowa Agl. Exp. Sta. Bullt. **27**: 130–135. *pl. 1.* 1895.

RUSSELL, H. L. A Bacterial Rot of Cabbage and Allied Plants. Wis. Agl. Exp. Sta. Bullt. **65**: 1–39. *figs. 1–12.* 1898.

SMITH, ERW. F. Centrbl. f. Bakt. Parask., u. Infektkr. **3** (II. Abt.): 284–291, 408–415, 478–486. *pls. 1–6.* 1897.

SMITH, ERW. F. The Black Rot of the Cabbage. U. S. Dept. Agl., Farmers' Bullt. **68**: 1–21. 1898.

SMITH, ERW. F. The Effect of Black Rot on Turnips. U. S. Dept. Agl., Bureau of Plant Industry, Bullt. **29**: 1–19. *pls. 1–13.* 1903.

STEWART, F. C., and HARDING, H. A. Combating the Black Rot of Cabbage by the Removal of Affected Leaves. N. Y. Agl. Exp. Sta. Bullt. **232**: 43–65. *pls. 1–2.* 1904.

Habitat relations. In recent years this cabbage disease has become well known as the most destructive and least controllable cabbage disease. It has been very generally reported from the states of the Mississippi Valley and eastward, extending into Canada as well. It is also well known in Europe. Possibly a form of the same disease may occur in Japan upon radishes.

It has been shown that infection takes place by way of the water pores of the host. In accordance with this fact, the climatic condition favoring the entrance of the organism is sufficient moisture in connection with warm days and cool nights. This would favor

the suffusion of the plant with water, and even the extrusion of droplets from the pores. Cool weather, warm, dry nights, and a dry soil offer a check to the disease. Smith's careful study of water pore infections has contributed greatly to our knowledge of the method of bacterial attack.

Symptoms. The first symptoms in the leaves are manifested[1] "at the margins, and consist of yellowing of all the affected parts except the veins, which become decidedly brown or black [see Fig. 24]. The leaves appear to have 'burnt edges.' From the margin of the leaf the progress of the disease is inward and downward through the stem. It usually enters the latter through the leaves.

A *B*

FIG. 23. BLACK ROT OF CABBAGE. (Photograph by F. C. Stewart)
A, inoculated and diseased plant; *B*, control, healthy

Subsequently the disease passes out again from the infected stem into healthy leaves and up into the center of the head. If leaves diseased at the edges are pulled off and examined where they join the stem, the groups of fibrovascular bundles, or leaf traces, in the petiole, are seen to be either free from the disease, in the early stage, or decidedly brown or even deep black from its presence. Leaves attacked in this manner fall off prematurely one after another, leaving in bad cases a more or less elongated stem covered with leaf scars and crowned with a tuft of small leaves. If the disease has entered the stem only on one side, that side is dwarfed and the head becomes one-sided." When young plants

[1] Smith. The Black Rot of the Cabbage, *l. c.*, p. 6.

are affected they may be killed. Any affected plants are prey to saprophytic organisms, and an offensive soft rot is then likely to result. Whether in the leaves or in the stem, the course of the

FIG. 24. A CABBAGE LEAF WITH BLACK ROT DEVELOPING FROM WATER PORE INFECTIONS. (Photograph by F. C. Stewart and H. A. Harding)

disease may usually be traced by a darkening of the fibrovascular bundles. Fig. 23 shows a healthy and a diseased plant, the latter as a result of artificial infection. Root infection may also occur.

This disease has been found upon apparently all of the common varieties of cabbage, in regions where the organism has gained a strong foothold. Turnips, cauliflower, kale, rape, and other species

of cultivated and wild cruciferous plants (such as mustard and charlock) are also known to be susceptible.

The organism, morphology and reactions. Upon gaining entrance through the water pores upon the margins of leaves this organism multiplies enormously. It is probable that a cellulose enzyme is slowly secreted, for in time masses of bacteria cause the progressive disappearance of the cell wall in contact with them. Through the vessels of the fibrovascular bundles they make most rapid advances. Affected bundles are indeed usually chambered pure cultures of this organism, and poured plate cultures, with proper precautions, show a remarkable purity. Upon cutting such affected

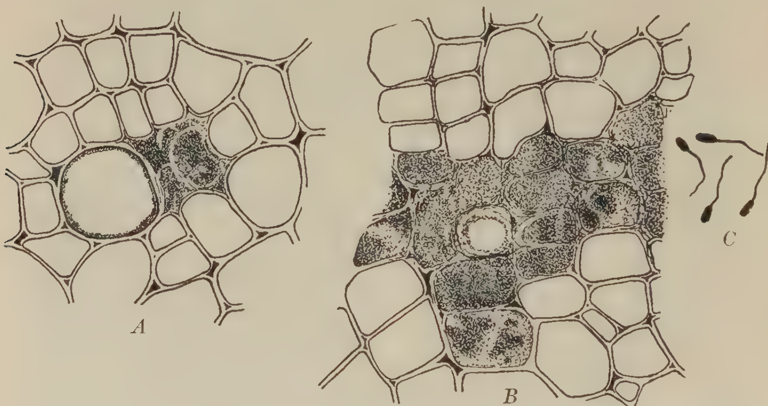


FIG. 25. *A* AND *B*, VASCULAR BUNDLES FROM TURNIP ROOT, SHOWING FORMATION OF BACTERIAL CAVITY; *C*, THE BACTERIA. (After Erw. F. Smith)

bundles the organism may ooze out in yellow droplets. In time practically any tissue of the host may be softened and disorganized (Fig. 25, *A* and *B*).

The organism is a short rod, with a rather long flagellum (Fig. 25 *C*). It is but slightly longer than broad in the tissues of the host, yet in artificial culture it may be several times as long as broad, measuring $0.7–3.0 \times 0.4–0.5\,\mu$. It is actively motile when young and nonmotile with age. It is commonly single or in pairs, and no spores have been found. It responds readily to stains.

It grows well in slightly alkaline bouillon, developing turbidity and a yellow precipitate. Gelatin is gradually liquefied, complete in fifteen days at 17° to 19° C., with yellow precipitate. On feebly

alkaline agar (22° Fuller's scale) colonies are circular, pale to wax yellow in color, margin entire. On potato there is a copious, flooding growth, with no browning of the substratum, and no odor. No acid is produced. All liquid cultures become gradually alkaline.

The optimum growth is believed to be at 25° to 30° C., and growth is feeble at 5° and 7° C. and at 37° and 38° C. It is killed by an exposure of ten minutes at 51° C. It differs from *Pseudomonas Hyacinthi*, to which it is related.

It is believed that this organism is able to pass the winter in the soil of fields in which it has been abundant. The suggestion has also been made that it may be disseminated through compost when cabbage refuse has contributed to the compost heap. Recently it has been demonstrated that some of these germs are able to live over on the seed for at least a year.

Control measures. The most dangerous sources of infection are the infested fields and the seed beds. Seed beds should be watched carefully, and no suspicious plants used. A rotation of crops is the sole means of eradicating the organism from a field once infested. Insects, snails, etc., may spread the disease to some extent. When leaves only have become infected, picking these and burning them may be of service, although in most instances this method has proved a failure. Seed treatment (mercuric bichlorid 1 to 1000, fifteen minutes; or formalin 1 to 200, twenty minutes) is advised.

III. WILT OF SWEET CORN

Pseudomonas Stewarti Erw. Smith

Stewart, F. C. A Bacterial Disease of Sweet Corn. N. Y. Agl. Exp. Sta. Bullt. **130**: 401–412. *pls. 1–4.* 1897.

Smith, Erw. F. Notes on Stewart's Sweet-Corn Germ (*Pseudomonas stewarti* n. sp.). Proc. Am. Assoc. Adv. of Sci. **47**: 422–426. 1898.

Smith, Erw. F. U. S. Dept. Agl., Div. Veg. Phys. and Path. Bullt. **28**: 1–153. 1901.

This disease was first discovered in the market gardens of Long Island, where much damage was done to sweet corn, *Zea mays*. It has since been found in Iowa and reported from parts of New York, so that it is doubtless widely spread. It is entirely distinct from the disease of field corn described by Burrill.[1]

[1] Burrill, T. J. A Bacterial Disease of Corn. Ill. Agl. Exp. Sta. Bullt. **6**: 165–176. 1889.

Symptoms. The external and internal symptoms of this disease are readily noted and distinctive. The affected plants die by wilting and drying, the water supply being cut off. Usually the leaves wilt one after another and the plant may live a month, but in some cases where the plants affected are a foot or less in height simultaneous wilting of the leaves may result, and the plants may die within four or five days of the first appearance of the disease. There is no discoloration, decay, or other complicating symptoms.

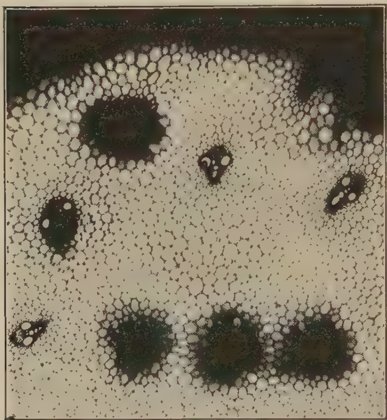


FIG. 26. CROSS SECTION OF STALK OF SWEET CORN, SHOWING BUNDLES OCCUPIED BY BACTERIAL COLONIES. (Photograph by F. C. Stewart)

The internal evidence of disease is equally clear. Upon cutting the stem lengthwise, the "fibrovascular-bundles appear," according to Stewart, "as yellow streaks in the white parenchyma; but in the stems of plants that have been dead for some time some of the bundles may be black instead of yellow. If the stem is cut crosswise and the cut surface exposed to the air for about five minutes, a yellow viscid substance exudes in drops from the ends of the vessels." Except for the greater accuracy of poured plates, pure cultures, which are essential, might be made by direct inoculation into tubes. The appearance of diseased bundles in cross and longitudinal sections is illustrated in Figs. 26 and 27.

Pathology. The organism is confined to the fibrovascular bundles exclusively, and appears to infest only the vessels. There is no disorganization of the tissue, and the pathological effect is therefore due, in large part, doubtless, to cutting off the transpiration stream. If there are secondary effects felt in the protoplasm of rather distant living cells, and brought about by diffusion of injurious excreted substances, it has not been demonstrated, so far as I am aware, in the case of any bacterial disease of plants. Field corn and pop-corn are resistant, but inoculation experiments with

sweet corn have been successful. The organism is probably spread by many mechanical agencies, and also distributed clinging to the seed.

The organism, morphology and reactions. The rods are short, almost ovoidal in form, ordinarily $1.3–1.6 \times .7–.8\,\mu$. On agar the colonies are more or less circular, becoming lobulated at the margins. With age the surface is granular. The color changes from yellowish white to bright yellow. Gelatin is not liquefied. A

FIG. 27. LONGITUDINAL SECTION OF STALK OF SWEET CORN, SHOWING A DISEASED BUNDLE. (Photograph by F. C. Stewart)

vigorous growth is produced on steamed potato, which in a week is iridescent. The potato turns brown in time.

In bouillon a turbidity is produced, and gradually a yellowish-white precipitate is formed. Yellow, surface-colony globules appear. In Uschinsky's solution there is a vigorous growth, litmus milk is slowly decolorized, and there is no coagulation. Gas is not produced, and the organism is aërobic and facultative anaërobic.

Control measures. There is great difference in the susceptibility of varieties of sweet corn, and this may be made use of where necessary. Only sound seed from uninfested regions should be employed. A rotation of crops is also an important precautionary measure.

IV. CROWN GALL OF APPLE, PEACH, AND OTHER PLANTS

Pseudomonas tumefaciens Erw. Smith and Townsend[1]

HEDGCOCK, GEO. G. Crown Gall, Hairy Root Disease of the Apple. Bureau Plant Industry, U. S. Dept. Agl. Bullt. **90** (Pt. II): 15–17. *pls. 3–5.* 1906.

HEDGCOCK, GEO. G. The Cross Inoculation of Fruit Trees and Shrubs with Crown Gall. Bureau Plant Industry, U. S. Dept. Agl. Bullt. **131** (Pt. III): 21–22. 1908.

SCHRENK, H. VON, and HEDGCOCK, GEO. G. The Wrapping of Apple Grafts and its Relation to Crown Gall Disease. Bureau Plant Industry, U. S. Dept. Agl. Bullt. **100** (Pt. II): 5–12. 1906.

SELBY, A. D. Diseases of the Peach. Ohio Agl. Expt. Sta. Bullt. **92**: 208–217. *pls. 5–6.* 1898.

SMITH, ERW. F., and TOWNSEND, C. O. A Plant Tumor of Bacterial Origin. Science, N. S. **25**: 671–673. 1907.

TOUMEY, J. W. An Inquiry into the Cause and Nature of Crown Gall. Ariz. Agl. Exp. Sta. Bullt. **33**: 1–64. *figs. 1–31.* 1900.

TOWNSEND, C. O. A Bacterial Gall of the Daisy and its Relation to Gall Formations on Other Plants. Science, N. S. (Abstract) **29**: 273. 1909.

Occurrence. The crown gall has thus far been found most commonly upon rosaceous plants (Rosaceæ), among these being included practically all of the stone, pomaceous, and bush fruits of this family, especially the various species of Prunus, Pyrus, Rubus, and Rosa. It has, however, been reported upon a variety of other plants, such as the grape (*Vitis* spp.), walnut (*Juglans nigra*), chestnut (*Castanea dentata*), poplar (*Populus alba*), willow (*Salix*), etc. Thus far, very little striking varietal resistance has been reported, although it is probable that the almost total absence of the disease under certain conditions is to be attributed in part to the difference in the susceptibility of the hosts as well as to diversity of external conditions. In general, nursery stock is more readily affected than older trees; but this may be due to greater opportunity for infection.

[1] It seems justifiable to give as conclusive the evidence thus far presented regarding the bacterial nature of the widespread crown gall. This evidence has been published by Smith and Townsend only as a preliminary paper and as abstracts of reports (one cited in the literature above) read before two societies at the meeting of the American Association for the Advancement of Science, and Affiliated Societies, Baltimore, December, 1908. The data and proofs orally presented, however, leave no reasonable doubt as to the bacterial cause of a large number of gall formations. It is not yet clear whether the galls of all such plants as apple, peach, grape, etc., are due to the particular species here described, or to closely related species. This, however, is a matter of far less present significance.

Upon different hosts the galls differ only slightly in form and appearance. Moreover, they are generally located near the surface of the soil in the region of the collar. A gall may, however, develop above the surface, or at some distance below, upon the smaller roots. Superficial galls are more common where the exposed portions are subject to such injuries as those produced by rodents or the implements used in cultivation.

Development of the gall. Published results regarding the development of these galls are based upon an examination of woody plants. It is probable that important differences will be found in the case of herbaceous plants. In general, the gall is an annual structure, even on woody plants, beginning its growth with exfoliation in the spring and maturing more or less by the time of leaf fall. When first observed the hypertrophies are small masses of rapidly growing, almost translucent tissue, nearly spherical in shape. According to Toumey, such galls, when developed superficially in cultures, may become greenish from the presence of chlorophyll. In any event, the clear white appearance is lost in a few months and the gall becomes warty and browned. During the latter part of the season, or during the winter, disintegration results, apparently by a normal process of decay. As a rule, such galls do not develop secondary galls from any portion of the old part but are entirely destroyed. Young galls may, however, spring from the collar or roots near the margin of the gall previously formed, and thus the wounds and injurious effects are intensified from year to year. In time the functions of the conducting tissues are so interfered with that death of the parts above follows gradually. In the South and Southwest, galls which begin to grow rather late in the season may continue their growth throughout another year.

According to Toumey "when the gall first begins its development, there is a pushing outward of a small area of the true cambium, which is transformed into large hypertrophied parenchyma cells. . . . In its youngest stages the tissue of the gall is a mass of parenchyma with numerous minute areas of rapidly dividing meristem scattered through it. The areas of meristematic tissue are centers of growth. . . . As the galls become older these centers of growth increase in size and others originate in

the newly formed parenchyma. The centers of these growths ultimately become most curiously twisted nodules of tracheides and woody fibers."

Galls upon relatively small roots may not attain more than a centimeter in diameter, while ordinarily on nursery stock, raspberries, etc., they may be as large as a walnut (Fig. 28). On the crowns of large trees they may be much larger.

Fig. 28. Crown Gall of Peach

Cross-inoculation experiments. It has cost no small amount of effort to determine the cause of crown gall. Toumey found a Myxomycete developing occasionally upon the cut surfaces of galls in impure cultures. He further observed appearances of the protoplasm in certain cells of the parenchyma of young galls suggesting stages in the development of the plasmodia. The evidence was not strong, however, and many pathologists reserved a final opinion regarding the nature of this disease. It was long apparent that the disease is infectious, and many experiments demonstrated that it could be conveyed from one susceptible plant to another by inoculation of the roots with macerated galls or by burying infected parts of diseased plants in the vicinity of healthy roots. The results of rather recent and extensive inoculation experiments by Hedgcock are summarized by him as follows:

"The soft galls from the almond, apricot, blackberry, cherry, peach, plum, prune, and raspberry have been transferred easily to seedlings of the almond, apricot, peach, and raspberry; less readily to those of the blackberry, cherry, plum, prune, and pear; and with great difficulty to seedlings of the apple, chestnut, walnut, and rose.

"The soft galls of the apple, chestnut, walnut, rose, and pear, as a rule, have not been transferred readily to any of the plants mentioned. Evidence has been obtained of a wide range of susceptibility in different varieties of the same plant. This has been noted in varieties of the apple, blackberry, cherry, chestnut, pear, and rose.

"The results of these experiments show that the opportunity presented for breeding and selecting races of plants resistant to this common and destructive disease is excellent."

Abundant, substantial proof has now been brought forward by Smith and Townsend demonstrating the bacterial nature of this disease. This work resulted from an examination of galls appearing naturally upon the Paris daisy, *Chrysanthemum frutescens*. From the last-named plant they were able to isolate a species of bacteria which proved to be pathogenic. They reported in 1907 more than three hundred successful inoculations under different conditions. In at least two series of experiments 100 per cent of the inoculations were effective, control plants remaining wholly free from galls under similar conditions. The organism was then described as *Bacterium tumefaciens*. It produces hypertrophies very readily in young tissues, particularly in fleshy organs, and it sometimes induces abnormal growths on the wounded parts of young cuttings. This organism was found to affect, with more or less similar lesions, many plants, including the tomato, tobacco, potato, sugar beet, grape, carnation, raspberry, peach, and apple. In four or five days after inoculation, swellings were evident, the latter on the daisy attaining an inch in diameter after a month or more.

According to Townsend, "this work has led to the isolation of pathogenic Schizomycetes from the galls of peach, hard galls of apple, hairy root of apple, hop, rose, and chestnut. The organisms obtained from the galls of these different plants are cross inoculable and are very similar, if not identical in size, shape, structure, and habits of growth on media with the organism from the daisy gall." It is further ascertained that galls produced by the daisy organism are very similar to those formed by the organism from the woody plants. It is apparent that it is too early to expect definite evidence as to the occurrence of biological forms or other more accentuated differences.

The organism. This species has already been studied with respect to its reactions on various media, and it is described as a short rod, motile by from one to three flagella. Cultivated on agar the translucent white, round colonies appear slowly at 25° C. The margins are smooth and dense. It produces no gas. Bouillon is not heavily clouded, and gelatin is not liquefied. The

organism grows very slowly at blood heat, but shows some growth at 0° C.

Control. It has been found very difficult effectively to cure trees upon which the gall has appeared. Removal of the gall with the tissues adjacent thereto, and the use of antiseptic washes, do not insure the complete isolation of the disease. It is evident, therefore, that there is difficulty in removing all diseased tissues. Since the gall develops promptly in nursery stock, it is readily detected at the time of transplanting, and such infected stock will, wherever possible, be discarded. Any injuries to growing trees at or near the surface of the ground will make infection easier, and consequently care should be taken in the cultivation of orchards.

V. OLIVE KNOT, OR TUBERCLE-DISEASE OF THE OLIVE

Pseudomonas Oleæ (Arc.) Trev.

PETRI, L. Untersuchungen über die Identität des Rotzbacillus des Oelbaumes. Centrbl. f. Bakt., Parask., u. Infektkr. **19** (Abt. II): 531–538. 1907.

PIERCE, N. B. Tuberculosis of the Olive. Journ. Myc. **6**: 148–153. *pls. 14–15.* 1891.

SAVASTANO, L. Tuberculosi, iperplasie e tumori dell' olivo. I e II Memoria, Ann. d. R. Scuola Sup. d'Agr. in Portici **5**: 131 pp. 1887.

SMITH, C. O. A Bacterial Disease of Oleander. Bot. Gaz. **42**: 301–310. 1906.

SMITH, ERW. F. Recent Studies of the Olive-Tubercle Organism. Bureau Plant Industry, U. S. Dept. Agl. Bullt. **131**: 25–43. 1908.

The olive knot was known in early times. It is not uncommon throughout the Mediterranean region, but it is perhaps most abundant in Italy. It seems to occur also in California. The knot is conspicuous from the development upon the smaller twigs and branches of a knob or tuberculate swelling. Small swellings may also occur on the leaves. The formation of the tubercle usually begins in the spring, and where the tubercle surrounds the branch the latter suffers considerable injury, and may eventually die.

Inoculation experiments made with pure cultures of the isolated organism have yielded characteristic infections, both in the experiments reported by Italian investigators and in those of Erwin Smith[1] in the United States. C. O. Smith has studied

[1] Smith, Erwin F. Bacteria in Relation to Plant Diseases **1**: 10.

a bacterial disease of the oleander in California, and from cultural characters of the organism isolated, as well as from inoculation experiments, he considers this organism to be *Pseudomonas Oleæ*. On the other hand, Erwin Smith would regard this as improbable, since he obtained no infections on oleander. He would seem to suggest that the organism isolated in California may have been the organism of crown gall (see p. 114).

VI. BEAN BLIGHT

Pseudomonas Phaseoli Erw. Smith

Beach, S. A. Bean Blight. N. Y. Agl. Exp. Sta. Rept. **11**: 553–555. 1892.
Smith, Erw. F. Description of Bacillus Phaseoli, n. sp. Proc. Am. Assn. Adv. Sci. **46**: 288–290. 1897.
Smith, Erw. F. The Cultural Characters of Four One-Flagellate Yellow Bacteria Parasitic on Plants. U. S. Dept. Agl., Div. Veg. Phys. and Path. Bullt. **28**: 1–153. 1901.
Whetzel, H. H. Some Diseases of Beans. Cornell Agl. Exp. Sta. Bullt. **239**: 197–214. *figs. 100–115.* 1906.

The bean blight, a disease far more common and destructive in the United States than has been generally believed, is due to this organism. The disease is common upon field, garden, and lima beans. It affects leaves, stems, and pods, but particularly the leaves and pods, upon which the symptoms are also most conspicuous. It is believed that diseased seed is the source of many early infections, whereas later infections may result through wounds in any green parts. On the foliage there appear irregular water-soaked patches, which later become, during dry weather, brown and papery. The disease progresses slowly, therefore it becomes evident, as a rule, only when the pods begin to form. Control is difficult, and must concern itself largely with seed selection and crop rotation. Seed from an affected field should not be planted. It is not enough to attempt to sort out healthy seed, when some of the lot are evidently diseased, for many which show no discoloration will be penetrated by the bacteria.

Fig. 29. *Pseudomonas Phaseoli* Erw. Smith (After Erwin F. Smith)

VII. HYACINTH DISEASE

Pseudomonas Hyacinthi (Wakker) Erw. Smith

SMITH, ERW. F. Wakker's Hyacinth Germ *Pseudomonas hyacinthi* (Wakker). U. S. Dept. Agl., Div. of Veg. Phys. and Path. Bullt. **26**: 1–45. *pl. 1.* Ibid. Bullt. **28**: 1–153. 1901.

WAKKER, J. H. Vorläufige Mitth. über Hyacinthenkrankheiten. Bot. Centrbl. **14**: 315–317. 1883.

WAKKER, J. H. Onderzoek der Ziekten van Hyacinthen, en andere bol-en Knolgewassen (1884): 4–13.

This organism, apparently confined to the Netherlands, is related to the three already discussed, yet it is entirely distinct. It produces a disease of hyacinths, entering the host through wounds or through the nectaries. The vascular system is chiefly affected, but the neighboring parenchymatous tissue is gradually involved, the middle lamellæ being the first portions of the walls to succumb. The organism may require a year in which to destroy the host.

VIII. BUNDLE BLIGHT OF SUGAR CANE

Pseudomonas vascularum (Cobb) Erw. Smith

COBB, N. A. Diseases of the Sugar Cane. New So. Wales Dept. Agl. (1893): 1–21.

SMITH, ERW. F. Ursache der Cobb'schen Krankheit. des Zuckerrohrs. Centrbl. f. Bakt. Parasitenk. u. Infektionskr. **13** (II Abt.): 726–729. 1905.

This organism is the cause of a disease of the sugar cane. It is not uncommon in Australia, and probably also in Java, Brazil, and other tropical countries. The organism attacks the fibrovascular bundles, — the etiology of the disease is not unlike that of *Pseudomonas Stewarti* Erw. Smith, — and a constant symptom is the excessive development in the bundles of a yellow gum.

IX. PSEUDOMONAS: OTHER SPECIES

Among other phytopathological species of special importance in certain regions, yet less well known, or imperfectly reported upon, are the following:

Pseudomonas Juglandis Pierce is a parasite of the English or Persian walnut (*Juglans regia*) in California.[1,2] Young nuts and shoots are affected, and the disease is one of much importance.

[1] Pierce, N. B. Walnut Bacteriosis. Bot. Gaz. **31**: 272–273. 1901.

[2] Smith, R. E. Report of the Plant Pathologist to July 1, 1906. Calif. Agl. Exp. Sta. Bullt. **184**: 232–236. *figs. 2–4.* 1907.

Pseudomonas malvacearum Erw. Smith. This parasite produces, through stomatal infections, water-soaked, angular areas (Fig. 30), known as angular leaf spot of cotton (Gossypium). Later these

FIG. 30. ANGULAR LEAF SPOT OF COTTON. (Photograph by Erwin F. Smith)

spots turn purple and finally become dry and brown. The disease is apparently widely distributed in the southern states, but the organism has not yet been fully described.[1]

X. PEAR BLIGHT

Bacillus amylovorus (Burrill) De Toni

ARTHUR, J. C. Diseases of the Pear. N. Y. Agl. Exp. Sta. Rept. **3**: 357–367. 1884.
ARTHUR, J. C. History and Biology of Pear Blight. Proc. Phil. Acad. Nat. Sci. (1886): 322–341. *pl. 3.*
BURRILL, T. J. Trans. Ill. State Hort. Soc. (1877): 114; ibid. (1878): 80.
BURRILL, T. J. Proc. Am. Assn. Adv. Sci. **29**: 583. 1880.

[1] Smith, Erw. F. Bacteria in Relation to Plant Diseases **1**: 95, 126.

BURRILL, T. J. Blight of Pear and Apple Trees. Ill. Indus. Univ. Rept. **10**: 583–597.
JONES, L. R. Studies upon Plum Blight. Centrbl. f. Bakt. Paras. u. Infektionskr. **9** (Abt. II): 835–841. 1902.
WAITE, M. B. Cause and Prevention of Pear Blight. Year Book U. S. Dept. Agl. (1895): 295–300.
WAITE, M. B. Pear Blight and its Control in California. State Hort. Com. of Calif. (Special Report) (1906): 1–20.
WHETZEL, H. H. The Blight Canker of Apple Trees. Cornell Univ. Agl. Exp. Sta. Bullt. **236**: 103–138. *figs. 50–83*. 1907.

Pear blight has been known in the United States for more than a century. Various common names have since been applied to this disease, determined largely by the host plant upon which it was found, and by the particular effect produced upon the host. Such names therefore as fire blight, twig blight, blossom blight, and other more or less similar designations have been applied.

FIG. 31. PEAR TREE PRACTICALLY DEAD FROM SEVERE ATTACK OF PEAR BLIGHT
(Photograph by H. H. Whetzel)

Geographical. This disease was first reported from the northeastern United States, but its occurrence was subsequently established in states to the south, west, and southwest, and by 1878 it was evidently very well established throughout the United States east of the Mississippi. Still later it became an important bacterial disease in the far West and Southwest. It is certainly distributed throughout the United States at present, but so far as is known, it does not occur in Europe or in Asia. There is every indication that the disease had its original home in the eastern United States, and its original host was doubtless some species of crab apple or thorn tree. Its gradual spread westward, therefore, was governed by the spread of civilization and the consequent greater contiguity of orchards,

Host plants. This species has received the name of pear blight on account of the fact that it is a more disastrous and more common disease upon the pear (*Pyrus communis*) than upon any other of its numerous hosts. It is also found as a parasite of the apple (*Pyrus Malus*), quince (*Cydonia vulgaris*), and of numerous species of native pomaceous plants, such as wild crabs (Pyrus) and hawthorn (Cratægus), and recently it has been found on the plum. There is considerable difference in the susceptibility of the various varieties of pears. The growing of Bartlett and many other desirable varieties of our common pears in the southern states and in the Mississippi Valley has been very largely given up on account of the destructiveness of this disease. Such varieties as the Bartlett, Seckel, and Le Conte are much more susceptible, at least in most sections of the country, than such as the Kieffer, Duchess, and Winter Nelis. The Oriental group in general is more resistant, although the several varieties are by no means free from the disease under conditions favorable for its development and propagation.

The pear blight is also a serious disease on apples, and there seems to be less difference in resistance among these fruits; nearly all of the standard varieties being more or less affected.

Symptoms. The pear blight is more commonly noticed during the early part of the season, when it appears in the form of twig blight throughout the blossoming period of both pears and apples. From two weeks to one month after the period of pollination the blossoms and tips may begin to wilt and show signs of general blackening, resulting finally in the complete blackening and death of all branches or spurs upon which flower clusters have been borne. In some instances scarcely a flower tip upon an infested tree is free from this general attack. As a matter of fact, the infection usually takes place at the time of blossoming and the disease is most abundantly distributed at that time, as will be shown later. Upon the pear the blight may continue to extend down the twig or the branch, the branch being entirely killed as it progresses; and in the course of some months it may have extended into the larger limbs, or into the main body of the tree (Fig. 31). Water shoots may also be affected both in the case of the pear and the apple (Fig. 32), and direct entrance to the body gained after a

very short period of growth. Nevertheless, under conditions more favorable for the host plant the blight may never extend more than a few inches, resulting merely in a tip pruning. In the case of the apple this twig blight is the rule, the disease apparently being usually unable to maintain itself in the larger branches. Young fruits of the apple, an inch in diameter, are

FIG. 32. WATER SPROUTS OF APPLE KILLED BY BLIGHT

frequently affected; and the copious growth of the organism gorges the fruit with the slime which may be exuded in droplets.

The progress of the disease is ordinarily very clearly indicated by the appearance of the bark. The growth of the organism within the tissues of the soft bark causes a water-soaked appearance, and finally a blackening and shriveling. The organism may, however, extend to a distance of several inches, or even a foot, below the water-soaked area. When the organism ceases to spread rapidly in the tissues, a sharp line of demarcation is noticeable, separating the dead from the healthy or comparatively

healthy tissues. In many instances the bark is broken, due probably to a gelatinizing process set up by the organism in the tissues of the host ; and from these ruptured areas there are exuded beads of a gelatinous or gummy nature, varying in color from milky white to brown or black. In order to secure cultures when the disease is not very active, it will be found desirable to bring affected twigs into the laboratory, placing them under a bell glass with the basal ends in a vessel of water.

The organism. The general life history of *Bacillus amylovorus* upon its host has become a landmark in our knowledge of bacterial diseases. The relations of this organism to the disease have been under constant observation for about thirty years. The true cause of the disease was first suspected in 1877 (Burrill), and the final discovery that pear blight is due to a species of bacteria was of unusual significance, as it shared with the discovery made by a Dutch botanist (Wakker) the honor of constituting the pioneer work with bacteria from a phytopathological standpoint.

The most careful observations and experiments indicate that the chief source of infection is by means of the visits of insects, especially bees, to the blossoms. The infection occurs, therefore, at the time of pollination. The bacillus multiplies very rapidly in the nectary of the flower, in which germs are directly inoculated by the visits of the insects. The rapid growth of the organism is such that after being inoculated into a blossom, and multiplying therein for twenty-four hours, it might be spread during the next day to many thousands of blossoms. From the nectary it gains entrance into the softer tissues of the bark and cambium, where it is very largely confined. Nevertheless, it is also true that infection may result through the growing twigs. Biting or piercing insects are doubtless of much importance in spreading the disease in this way. Injuries and sometimes, perhaps, even water pores may be the seats of infection. In general, however, it is certainly true that the presence of germs upon the surface of healthy tissues would not result in the production of disease in those parts.

The bacillus winters over, under favorable conditions, in relatively few affected branches, under conditions where moisture is sufficient and protection from drying out adequate. It is from such wintered-over areas as centers that the disease is spread to

the blossoms the following spring. With the return of growing conditions, fermentation may be set up and beads of the gummy exudation produced. Since the beads contain countless quantities of the bacillus, insects readily spread it to some blossoms; thence it is promptly carried by bees to greater distances. The organism,

FIG. 33. PEAR FRUIT INFESTED WITH THE BLIGHT ORGANISM; BEADS EXUDED IN MOIST CHAMBER. (Photograph by H. H. Whetzel)

however, is not very resistant to conditions. It is killed by very brief exposure to sunlight and by a period of drying. This latter, however, seems remarkable, in view of the general experience that no amount of cold can act unfavorably upon this organism. It is possible, however, that the effect of cold in the absence of moisture may be as disastrous as drying out.

The characteristics of this organism according to Whetzel are as follows:

Single cells of the organism direct from the tree are oval, 1.5 to 2 μ long, and somewhat more than half as broad (Fig. 34). They occur single or attached, several end to end. Upon various culture media they are more commonly single or in pairs, although sometimes in short threads, and in all cases motile in fresh cultures.

FIG. 34. *BACILLUS AMYLOVORUS* FROM APPLE FRUIT; SIMPLE STAIN

On gelatin growth is slow, requiring three to five days for the appearance of colonies, the latter being globose to lenticular, yellowish, liquefying the medium very slowly.

On agar the surface colonies appear more rapidly, being evident the second day, and attaining a diameter of from 2 to 3 mm. by the fourth or fifth day. They are white and granular, or cloudy, with a sharply defined white center; the margins are entire or slightly wavy, with a dense white center. Immersed colonies are globose or lens-shaped, and opaque-yellowish.

In bouillon a cloudiness is produced after twenty-four hours, and this is accompanied by slight acidity; after forty-eight hours there is greater cloudiness, with more or less persistent flocci, the medium becoming alkaline, and in time showing a tendency to clear. In sugar-free bouillon the liquid remains clear for twenty-four hours, except for slight sediment. It is neutral at first, becoming cloudy and alkaline after some days. In milk no change is evident until the third or fourth day, when thickening begins, which increases to fifth or sixth day. The product finally becomes subgelatinous, and in ten days there is a clear liquid above. This is at first acid, becoming slightly alkaline. Litmus milk is unchanged.

On slanting agar tubes growth in twenty-four hours is moderate, opalescent, spreading slowly, producing turpidity in the water of condensation; growth not viscid.

On gelatin stab cultures growth is similarly slow, and beaded or granular along the needle path; surface growth with irregular or erose margin, center thin and granulose; liquefaction slow, crateriform and stratiform.

Control. The control of pear blight was for a long time considered impossible, but careful study under various conditions

(particularly the work of Waite) has shown that this disease may be controlled or even practically eradicated in large regions. The essential step consists in pruning out the blight in situations where it may winter over. If all of the blight could be thoroughly pruned out of the orchard during the fall and winter, there would

FIG. 35. BLIGHT CANKER ON TRUNK OF APPLE, FROM INFECTED PRUNING KNIFE. (Photograph by H. H. Whetzel)

probably be no opportunity for infection the following season, except from distant orchards. In practice the pruning out of the blight during winter is not an easy process, and it requires the greatest care and keenest eyesight. It would be necessary to go over the orchard several times, the final observation being made only a short time before the opening of the blossoms.

Pruning during the growing season is also practiced, but it is less reliable. Such pruning has not proven a great success on account of the fact that infection may be constantly taking place. Moreover, when the blight is rapidly extending in a limb or trunk, it is difficult to determine the extent of the region affected. In dealing with this organism, in general, all possible bacteriological precautions must be taken. Carelessness in the pruning of nursery stock may actually result in spreading the disease to practically all of the young trees. The knife should be promptly applied wherever a limb or trunk may be saved, and antiseptic precautions should be taken.

XI. WILT OF CUCURBITS

Bacillus tracheiphilus Erw. Smith

SMITH, ERW. F. Bacillus tracheiphilus, sp. nov., die Ursache des Verwelkens verschiedener Cucurbitaceen. Centrbl. f. Bakt., Parasitenk. u. Infektskr. **1** (Abt. II): 364–373. 1895.

The wilt of cucurbits was first reported about 1893 (Smith) and it is now the most common and perhaps the most serious disease among cucurbitaceous plants in the United States. It was at first known (to pathologists at least) in the northeastern states, but it is now common upon several hosts in Missouri, Colorado, and other western states. Cucumbers and melons would seem to be most susceptible, although pumpkins and squash may be attacked. Weather conditions do not seem to affect materially the abundance of this disease.

Symptoms. The general symptoms are simple and striking. These consist of a progressive wilting of the host. If infection takes place upon the central stem, the wilting in the whole vine follows promptly. If, however, infection is in the distal parts of branches, there is gradual wilting back to the main stem. Then the remaining branches promptly show the effect. In the tissues there is at the time of wilting very slight, if any, evidence of a change in appearance. In no case is there the development of odors, or of decay in the usual sense.

Infection and spread of the disease appears to result almost wholly through biting insects. The organism is found massed primarily in the vessels of the xylem. At first the spiral vessels

are the seat of action, and later the pitted vessels are infested. In late stages of the disease the lesions may be considerable, the bundle system being broken down and cavities formed in the adjacent tissues. The lesions are also very noticeable when the organism has gained entrance to the fruit.

The organism is a rod averaging two or three times as long as broad, 1.2–2.5 × .5–.7, often adhering in twos, and rapidly motile only when young (Fig. 37). The rods are readily stained

FIG. 36. BACTERIAL WILT OF MELONS. (Photograph by H. H. Whetzel)

with carbol fuchsin, but the flagella are not so readily demonstrated. Growth in bouillon results in a turbidity, and in potato decoction viscosity is developed with age. Coagulation of milk does not occur, and after weeks no viscosity is evident. On gelatin growth is slow, and there is no liquefaction. Similarly, on agar the clear, or milk-white, colonies spread slowly. Stab cultures develop a slight growth throughout the extent of the stab, with lobulated projections. On slices of potato there is a

vigorous gray-white film, and no changes are manifest in the substratum. The organism is aërobic and perhaps facultative anaërobic. There is no gas production.

The contents of the vessels affected are slightly alkaline, and alkaline media are apparently preferred. This organism is sensitive to high temperatures, 43° C. or over being fatal in ten minutes. Death results in fifteen minutes in dry air, and the normal life of a culture is from a few weeks to several months.

Fig. 37. *Bacillus tracheiphilus*

Numerous well-controlled infection experiments have established the causal connection of the bacillus with the symptoms of this disease.

XII. SOFT ROT OF CARROT AND OTHER VEGETABLES

Bacillus carotovorus Jones

Harding, H. A., and Stewart, F. C. A Bacterial Soft Rot of Certain Cruciferous Plants and Amorphophallus simlense. Science, N. S. **16**: 314–315. 1902.

Harrison, F. C. A Bacterial Disease of the Cauliflower (*Brassica oleracea*) and Allied Plants. Ont. Agl. Exp. Sta. Bullt. **137**: 1–28. *figs. 1–18.* 1904.

Jones, L. R. A Soft Rot of Carrot and Other Vegetables. Vermont Agl. Exp. Sta. Rept. **13**: 299–332. *figs. 1–10.* 1901.

Potter, M. C. Ueber eine Bakterienkrankheit der Rüben (*Brassica Napus*). Centrbl. f. Bakt., Parasitenk. u. Infektionskr. **7** (Abt. II): 282–288, 353–362. 1901.

Spieckermann, A. Beitrag zur Kenntnis der bakteriellen Wundfäulnis der Kulturpflanzen. Landw. Jahrb. **31**: 155–178. 1902.

Van Hall, C. J. J. Bijdragen tot de Kennis der Bakterieelle Plantenziekten: 176–184. 1902.

Occurrence and effects. This bacillus appears to be one of the most common and widespread of the species parasitic upon plants. It was not accurately studied until 1901, but has since received attention from a number of investigators in different parts of Europe and America. It seems safe to say that it is the chief producer of that type of disease known as soft rot in vegetables.[1]

[1] Through the kindness of Mr. H. A. Harding, of the New York Agricultural Experiment Station, I have been able to see the proof of a bulletin by H. A. Harding and W. J. Morse on the morphology and cultural characters of this organism. This study establishes in a conclusive manner the fact that many diseases of vegetables previously referred to other organisms are in reality properly caused by this species, and the data here presented are largely based upon the study indicated.

The bacteria invade the intercellular spaces of the host, and subsequently the tissues are rapidly disorganized. This disorganization is apparently due to an enzyme which attacks particularly the middle lamella. A large number of inoculation experiments have been made, and it is clearly shown that these bacteria are able to produce a form of soft decay in a great variety of plants. No other organism yet found has such a wide range of host plants.

Morphology and cultural characters. The bacillus is in the form of short or long rods or chains. According to Jones it measures .6–.09 × 1.5–5 μ, the majority, however, measuring .8 × 2 μ. No endospores are produced, and it possesses from two to ten peritrichiate flagella.

FIG. 38. *Bacillus carotovorus* Jones. (After L. R. Jones)

Upon slanting tubes of agar an abundant growth is produced. This is filiform to spreading, smooth or contoured, and opaque to opalescent in appearance. It also grows well on potato. Gelatin is promptly liquefied, under ordinary circumstances, at 20° C. Usually liquefaction begins on the second day and is complete in six days; yet months may be required. In bouillon a pellicle is often formed. In other cases there is merely a clouding, or finally the development of a flocculent precipitate. Milk is usually coagulated by the third day, and this is so slowly peptonized that the action may not be complete for several months. Litmus milk is rendered acid, and the power of indol production is possessed to a feeble extent.

The organism reduces nitrates in nitrate broth to nitrites. The thermal death point is about 48 to 50° C. It is also important to note that with a majority of the strains gas is produced in small amounts with dextrose, lactose, and saccharose. In this gas-producing character the forms of the organism from a large number of sources show a certain variation, however, which reaches an extreme in the form producing soft rot of the calla lily, in which case no gas is produced from any of the sugars mentioned. The calla lily organism is tentatively retained as a distinct species. It represents, at any rate, an extreme form of the *Bacillus carotovorus* so far as it is at present known.

XIII. SOFT ROT OF THE CALLA

Bacillus aroideæ Townsend

TOWNSEND, C. O. A Soft Rot of the Calla Lily. U. S. Dept. Agl., Bureau Plant Industry, Bullt. **60**: 1–44. *pls. 1–9.* 1904.

This organism, very closely related to the preceding, has been found to be the cause of a serious soft rot of the calla lily, destroying the plants at about the time of flowering. The seat

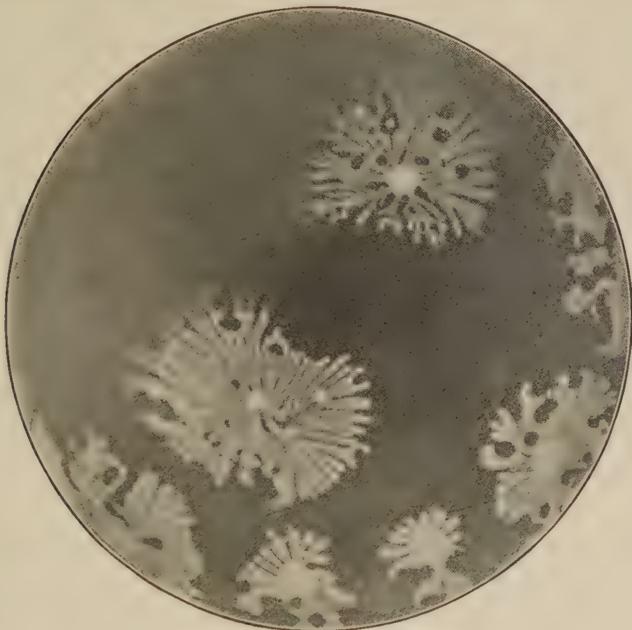


FIG. 39. ISOLATION CULTURE OF *BACILLUS AROIDEÆ* TOWNSEND. (Photograph by C. O. Townsend)

of the disease is principally in the corms, petioles, and flower stalks. If inoculated into a wound, the bacillus will produce a rot in many raw vegetables, and also in some green fruits. The cultural characters have been indicated. According to Townsend it produces on agar very characteristic radiate colonies (Figs. 38, 39) at or near the optimum temperature. The rot in the calla may be prevented by a careful selection of the corms and by changing the soil in the beds every three or four years.

XIV. WILT OF SOLANACEÆ

Bacillus solanacearum Erw. Smith

SMITH, ERW. F. A Bacterial Disease of the Tomato, Egg Plant and Irish Potato. U. S. Dept. Agl., Div. Veg. Phys. and Path. Bullt. **12**: 1–26. *pls. 1–2.* 1896.

SMITH, ERW. F. The Granville Tobacco Wilt. U. S. Dept. Agl., Bureau Plant Industry, Bullt. **141** (Pt. II): 17–24. 1908.

This is a germ which, in the United States, causes an important wilt and drying up of potatoes, tomatoes, and eggplants. In the far South it is particularly destructive to tomatoes. It has also been found in Europe and Asia. When potato vines are affected there is a blackening of the fibrovascular system of the tuber, and eventually a black rot may set in. The organism is aërobic and an alkaline reaction is produced. No gas is evolved, and gelatin is not, or only very slightly, liquefied. Recently it has been found that this organism produces also the Granville tobacco wilt.

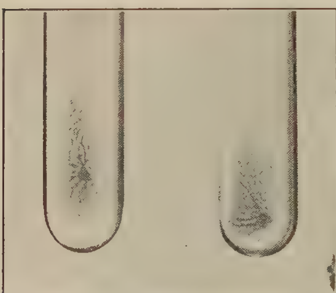


FIG. 40. SUBCULTURE OF *BACILLUS AROIDEÆ* ON AGAR SLANT. (Photograph by C. O. Townsend)

XV. BACILLUS: OTHER SPECIES

Among other disease-producing organisms of this genus may be mentioned the following:

Bacillus Hyacinthi-septicus Heinz,[1] causing rapid death of cultivated hyacinths.

Bacillus Cubonianus Macch.,[2] said to be the cause of an important leaf and twig disease of the mulberry, especially in France and Italy.

[1] Heinz, A. Zur Kenntniss der Rotzkrankheiten der Pflanzen. Centrbl. f. Bakt. u. Parasitenk. **5**: 535–539. 1889.

[2] Macchiati, L. Sulla biologia del Bacillus Cubonianus, sp. nov. Malpighia **5**: 289–301. *pl. 21.* 1891.

CHAPTER X

PHYCOMYCETES

The Phycomycetes are commonly called the algal-like fungi. They are very diverse both with reference to the characteristics of the vegetative and of the reproductive stages. The habits of these forms, moreover, are so varied that a discussion of such peculiarities may be postponed until the individual families are described. The lower forms show very little differentiation or complexity of vegetative parts, and the fungous body may indeed consist of a single simple cell. In other forms the fungous body possesses short branches or thread-like parts, which may be designated *hyphæ*. In the higher forms there is a well-developed mycelium, or system of branching hyphæ. These vegetative hyphæ are commonly siphonaceous (nonseptate), but sometimes cross walls (septa) are produced. In fact, there are families in which the mycelium is constantly siphonaceous until the reproductive cells are cut off, and cross walls occur only in conjunction with spore development. In other cases the hyphæ are siphonaceous when young, becoming generally septate with age.

The methods of reproduction are either by means of nonsexual or sexual spores. The nonsexual spores are produced either within differentiated portions, usually tips of branches, in which case these differentiated parts are termed sporangia; or the spores (conidia) may be produced upon hyphæ, in which case the latter are known as conidiophores. In some genera the conidia also become sporangia germinating by the production of motile spores, zoospores. Sexual reproduction by the union of differentiated cells (gametes) is common in the higher forms only, and the gametes may be equal or unequal in size. The higher forms, however, constitute the majority of these fungi.

The Phycomycetes contain seven orders. Two of these, Ancylistales and Monoblepharidales, are small groups of water fungi. One order, the Mucorales, is an unusually interesting group,

composed, however, largely of saprophytic organisms, and a fourth order, Entomophthorales, contains forms which are for the most part parasitic upon insects. There remain therefore three orders which are important from the standpoint of diseases in plants, viz., Chytridiales, Saprolegniales, and Peronosporales.

I. CHYTRIDIALES

Farlow, W. G. The Synchytria of the United States. Bot. Gaz. **10**: 235–245. *pl. 4.* 1885.
Harper, R. A. Cell-Division in Sporangia and Asci. Ann. Bot. **13**: 467–525. *pls. 24–26.*
Kusano, S. On the Cytology of Synchytrium. Centrbl. f. Bakt., Paras. u. Inf. **19** (Abt. II): 538–543. *pl. 1.* 1907.
Nowakowski, L. Beitrag z. Kenntnis d. *Chytridiaceen.* Cohn's Beiträge z. Biol. d. Pflanzen **2**: 73–100, 201–219. *pls. 4–6, 8–9.* 1876.
Rytz, Walter. Beiträge zur Kenntnis der Gattung Synchytrium. Centrbl. f. Bakt., Paras. u. Inf. **18** (Abt. II): 635–655, 799–825. 1907.
Schroeter, J. Die Pflanzenparasiten aus der Gattung *Synchytrium.* Beiträge z. Biol. d. Pflanzen. **1**: 1–132. *pls. 1–3.* 1870.
Schroeter, J. Chytridineæ. Pflanzenfamilien (Engler and Prantl) **1** (1* Abt.): 64–87. *figs. 49–71.* 1892.
Zopf, W. Ueber einige niedere Algenpilze. 1887. Halle.

In a consideration which might include several hundred fungi of greatest economic importance, as disease-producing organisms of the flowering plants, doubtless no mention would be made of the above order. The order should, however, receive at least casual attention at the hands of the student, owing to the important position which it occupies as the lowest of the true fungi. It is a striking fact that a considerable majority of these lower fungi are parasitic upon protozoa, algæ, and other fungi. Some, however, are parasitic upon higher plants.

These plants are all very simple, and there is no member of the family which possesses a true mycelium, although delicate branches of the fungous body occur. Reproduction is accomplished by means of motile spores, or swarm cells, produced in sporangia. In higher forms cell fusions occur. It is not certain what these fusions denote.

II. SYNCHYTRIACEÆ

In this family are included the majority of the Chytridiales parasitic upon higher plants. They occur for the most part only

upon plants growing in moist situations. A motile spore, zoospore, comes to rest upon an epidermal cell, and penetration doubtless results after a minute perforation is made, by the streaming through of the protoplasmic body. There are no evidences of a mycelium. The presence of the parasite in the epidermal cell may in time cause a minute gall-like abnormality of the host. The small galls are sometimes so numerous as to give the host the appearance of being affected by a rust fungus.

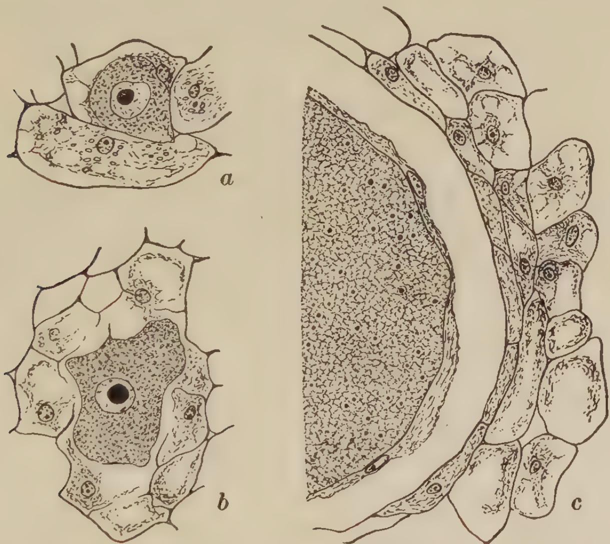


FIG. 41. SYNCHYTRIUM ON PUERARIA, STAGES IN THE FORMATION OF THE POLYNUCLEATE FUNGOUS BODY AND THE LYSIGENOUS CAVITY. (After Kusano)

The simple protoplasmic mass resulting from the growth of the penetrating swarm spore becomes either a fruit body, sorus, or a resting spore; in the latter case it becomes a fruit body ultimately, and this, at maturity, breaks up into numerous sporangia, and may therefore be termed a sorus, each sporangium eventually producing swarm cells.

Harper has studied from a cytological point of view the development of *Synchytrium decipiens* Farl., and from this study may be distinguished seven more or less distinct stages in the life cycle of this organism: (1) after the swarm spore comes to

rest and penetrates the epidermal cell of the host there is considerable growth in this single cell of the fungous, vegetative body; (2) multiplication of the nuclei in the vegetative body until a considerable number is formed; (3) progressive cleavage in the multinucleate body from the surface inward, such that uninucleate bodies (termed protospores) are produced, accompanied with marked shrinkage of the segments; (4) growth, increase in size of the protospores, followed by nuclear divisions; (5) the development of cell walls about the multinucleate spores, food storage, and passage into a ripened or resting condition; (6) germination by the production of a sporangium from each multinucleate spore, each sporangium producing a number — usually eight to twelve — of the uninucleate, uniciliate spores; (7) the active motile stage.

In a recent study Kusano reports that a Synchytrium on Pueraria, and also *Synchytrium decipiens*, affect only nonchlorophyllous cells of the mesophyll. In each he finds that the cell wall of the affected cell (and in time of neighboring cells) is dissolved. Eventually considerable lysigenic cavities are formed in which the fungous body lies "encased by the symplast of the host" (Fig. 41).

Synchytrium. In this genus the fruit body, upon reaching maturity, forms no highly resistant cell wall about itself, but by immediate differentiation of the protoplasmic contents becomes the sporangial sorus.

Pycnochytrium. The fruit body is a thick-walled resting spore, which after a period of inactivity germinates by the protrusion of its contents in the form of a thin-walled sporangial sorus. The sporangia produce uniciliate swarm spores.

III. CRANBERRY GALL

Synchytrium Vaccinii Thomas

HALSTED, B. D. Some Fungous Diseases of the Cranberry. N. J. Exp. Sta. Bullt. **64**: 1–40. *figs. 1–18.* 1889.

SHEAR, C. L. Cranberry Diseases. Bureau Plant Industry, U. S. Dept. Agl. Bullt. **110**: 1–64. *pls. 1–7.* 1907.

It attacks young stems and leaves as well as flowers and fruit. The small galls, reddish in color, are produced on the surfaces of the parts affected in great numbers. The fungous body consists

of a cell (Fig. 42), which becomes a spore, or properly a sporangium, producing upon germination a mass of swarm spores. These spores, being dependent upon abundant moisture for their distribution, may be rendered more or less ineffective by withholding water from the cranberry plants during the winter. This fungus also occurs upon other ericaceous plants more or less closely related to the cultivated cranberry.

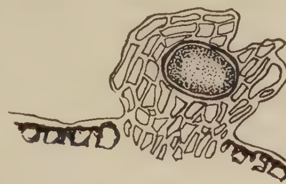


Fig. 42. Blackberry Gall: Resting Spore Stage

IV. PYCNOCHYTRIUM GLOBOSUM (Schroet.) Schroet.

This is a parasite common in Europe and America on many families of flowering plants. In the United States it has been found on plants growing in the peat bogs of the eastern states, some of the hosts observed being a species of violet, wild strawberry, blackberry, and maple seedlings. It causes the development of small but noticeable yellow or reddish galls.

The entrance of the swarm spore into an epidermal cell is, as indicated above, followed by general growth of the protoplasmic mass. The affected epidermal cell may become somewhat invaginated, but the enlargement due to the growth of the fungous cell within is such as to give the appearance of a minute gall. The resting spore is shown in Fig. 42 as it appears in midsummer. Later there results, as indicated, the sporangial sorus, each sporangium of which, upon germination, produces the characteristic uniciliated swarm spores.

V. CHYTRIDIALES: OTHER SPECIES

Among other Synchytriaceæ more or less commonly found in the United States are *Synchytrium decipiens* Farl. on the hog peanut, *Amphicarpa monoica*; *Synchytrium fulgens* Schroet. on the evening primrose, *Œnothera biennis*; *Pycnochytrium aureum* (Schroet.) Schroet. occurring upon numerous hosts; and *Pycnochytrium Myosotidis* (Kühn) Schroet. on certain Boraginaceæ and Rosaceæ. In a different family, Oochytriaceæ, may be included some interesting parasites of economic plants. These fungi

are certain members of the genus Urophlyctis.[1, 2] *Urophlyctis leproides* (Trabut) Magn. occurs on root outgrowths of the beet, *Beta vulgaris; Urophlyctis pulposa* (Wall.) Schroet. attacks leaves and stems of species of Chenopodium and Atriplex; and *Urophlyctis Alfalfæ* (v. Lagerh.) Magn. is found upon the roots of alfalfa, *Medicago sativa*, in South America and in Germany.

VI. SAPROLEGNIALES

The Saprolegniales are commonly called water molds on account of the fact that the majority of these fungi occur in the water, usually in ponds and streams, upon dead insects and other small animals, or sometimes upon other organic matter. One or more species attack fish, producing important diseases. A few members of the order, however, are not properly water molds, being found upon plants in moist places, some parasitic and some saprophytic. In the aquatic forms there is a considerably branched mycelium, habitually without septa, except where spore-producing parts are cut off. The hyphæ are frequently of large diameter and readily evident to the unaided eye. Nonsexual spores are produced in terminal sporangia. Upon liberation the spores usually become motile. Sexual reproduction is by means of unequal gametes, produced in oogonia and antheridia. The latter are sometimes wanting; moreover, when present there are cases (certain aquatic forms) where they are apparently functionless.

Pythiaceæ. The Pythiaceæ include such members of the Saprolegniales as are important in plant pathological study. The family has some characters which seem to indicate that they might with equal propriety be placed in the order next discussed, Peronosporales. The species which are of interest in this connection are those which cause damping-off, rot, or somewhat similar diseases in seedlings, or in delicate plants. This family differs from the remaining coördinate members of the order in the complete differentiation of the sporangia from

[1] Magnus, P. Ueber eine neue unterirdisch lebende Art der Gattung Urophlyctis. Ber. d. deut. bot. Ges. **19**: 145–150. *pl. 27.* 1901.

[2] Magnus, P. Ueber die in den knolligen Wurzelauswüchsen der Luzerne lebende Urophlyctis. Ber. d. deut. bot. Ges. **20**: 291–296. *pl. 15.* 1902.

the general vegetative hyphæ, and also in the production of other nonsexual spores, conidia, borne upon hyphæ, which spores germinate by means of a germ tube, and not by the production of motile spores. The antheridia are always functional, and the process of fertilization is apparently exactly the same as in the majority of the Peronosporales. Pythium and Pythiacystis are important genera.

VII. A DAMPING-OFF FUNGUS

Pythium de Baryanum Hesse

ATKINSON, GEO. F. The Potting Bed Fungus. Cornell Univ. Agl. Exp. Sta. Bullt. **94**: 234–247. *pl. 1.* 1894.

HESSE. Pythium de Baryanum, ein Endophytischer Schmarotzer. 1874. Halle.

MIYAKE, K. The Fertilization of Pythium de Baryanum. Ann. Bot. **15**: 653–667. *pl. 36.* 1901.

WARD, H. MARSHALL. Observations on the Genus Pythium (Pringsh.). Quart. Journ. Mic. Sci. **23**: 485–519. *pls. 34–36.* 1883.

Habitat relations. This species is, perhaps, from an economic point of view, the most important in the order. It is very common in greenhouse and garden soil both in Europe and America, and it is a cause of one of the various greenhouse maladies known as damping-off in seedlings. The conditions which favor the development of the fungus are a considerable degree of warmth, abundant moisture, and weakened condition of the seedlings. It is especially common when the plants are being grown in a very crowded condition. While most common in the greenhouse, it may affect the crop in the field as well. This fungus infests a variety of seedlings, but those of the cress, cucumber, sunflower, and others are particularly susceptible. White clover, several crucifers, corn and other members of the grass family are likewise included among the hosts.

Symptoms. The effects of this fungus may be evident upon the seedlings a few days after germination. The point of attack is ordinarily at or near the surface of the ground. The tissues of the affected region promptly lose their turgidity and usually appear water soaked (Fig. 43). When the tissues collapse the seedlings fall prostrate, and then the mycelium invades the remainder of the plant, if the latter is kept moist by contact with the damp soil.

FIG. 43. BEAN SEEDLINGS ATTACKED BY PYTHIUM
(Photograph by H. H. Whetzel)

The fungus. The mycelium, like that of most Peronosporaceæ, is delicate, more or less variable in diameter, and much branched. The branches are, for a time, at least, smaller than the parent hyphæ. The protoplasm is densely granular in the growing

portions. The hyphæ are apparently intercellular at first and afterwards intracellular.

Terminal or intercalary spherical sporangia are sparingly produced. These are usually persistent, and may be from three to five times the diameter of the hyphæ. During germination a short tube is developed at one side, and through this the mycelium migrates, forming a kind of swarm sphere within which it breaks up into bean-shaped masses, which are set free as zoospores with two lateral (Hesse figures only one) cilia. Thicker walled sporangia-like bodies, called conidia, are also produced. These are deciduous, and germinate immediately by forming zoospores.

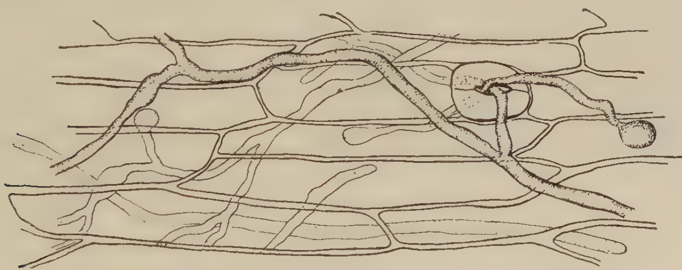


Fig. 44. Mycelium of Pythium invading Tissues

Thick-walled resting conidia also appear, and these eventually germinate by means of a germ tube.

The oogonia, or egg-bearing gametes, are formed either as terminal or intercalary enlargements, and are of much the same form as the sporangia. When two or three times the size of a hypha they are cut off from the vegetative cells. The protoplasm is gradually differentiated into a central denser portion, ooplasm, or oosphere, and a less dense peripheral "periplasm." A coincident development of an antheridium or male gamete takes place, the latter arising either as the enlarged terminal portion of a separate antheridial branch (from the same or from a different hypha), or as a lateral cell cut off directly adjacent to the oogonium. More than one antheridium may be present, each coming in contact with the oogonium. From an antheridium a fertilization tube grows into the oosphere, and through this tube a nucleus and some cytoplasm pass in, and the nucleus fuses with the nucleus of the oosphere (Fig. 45). This process

has been carefully studied, and the evidence must be accepted. Subsequently, a thick wall forms about the oosphere, which now properly becomes the mature egg, or oospore, measuring ordinarily 25–35μ in diameter. The development of an oospore may be completed, under favorable conditions, in a single day.

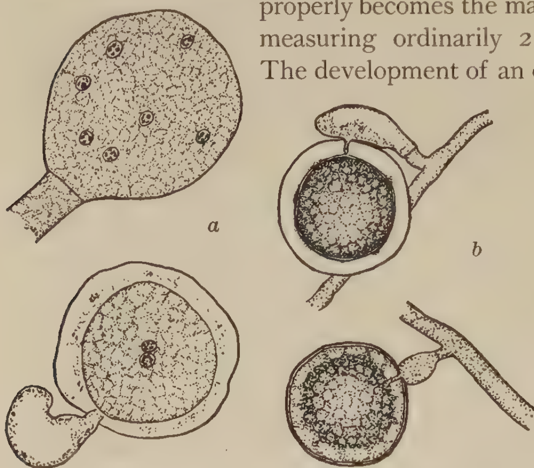


FIG. 45. SEXUAL REPRODUCTION IN PYTHIUM (*a*, after Miyake)

Since this fungus may readily continue its growth into dead tissues it may be cultivated indefinitely in Van Tieghem cells or in specially devised culture chambers, and the various reproductive processes may therefore be carefully followed. It is evident that with care the fungus might be isolated and grown in pure cultures. The material of the genus Pythium from various hosts and localities should be carefully studied and compared under control conditions, as there is much doubt concerning the validity of species.

VIII. BROWN ROT OF THE LEMON

Pythiacystis Citrophthora R. E. Smith

SMITH, R. E. A New Fungus of Economic Importance. Bot. Gaz. **42**: 215–221. *figs. 1–3.* 1906.

SMITH, R. E. The Brown Rot of the Lemon. Calif. Agl. Exp. Sta. Bullt. **190**: 1–70. *figs. 1–29.* 1907.

Occurrence. The brown rot of the lemon is a disease which has become very prominent in the region of lemon production in California during the past few years. It affects more or less every operation having to do with lemon production and marketing, and at the time of the investigations which were undertaken in California for its control it seemed to threaten the stability of this industry. The brown rot may be found in the orchard,

in the packing house, and in storage conditions. From the description subsequently given it may be readily distinguished from forms of decay due to common mold fungi. It is most serious in connection with lemon growing, but the fungus producing the disease may also affect to a slight extent at least the orange, pomelo, and other citrous fruits. In the orchard the disease may be found upon fruit which has fallen, or that which is hanging very close to the moist soil. It is most abundant during wet weather, or following irrigation, and is therefore intensified where the soils are heavy. It is estimated that under favorable conditions for the fungus a box of lemons per tree is no extraordinary loss.

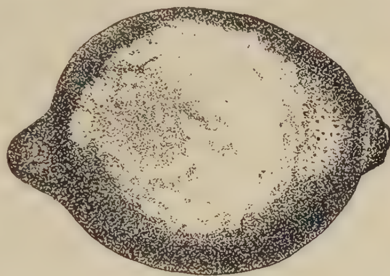


Fig. 46. Brown Rot of Lemon (After R. E. Smith)

Symptoms. The first indications of the trouble may be noted in a brownish or purplish discoloration of the rind, showing light on the greener fruit, and darker on the yellow fruit. Both young and old, vigorous and weak fruits alike are affected, and the disease is particularly characterized by a marked and peculiar odor, by its rapid spread from fruit to fruit, in the packing house, or while stored in boxes, and by the presence of small flies wherever the affected fruit is stored in quantity. After storage for a week or ten days there may develop upon the affected lemons a white mold-like growth (Fig. 46), and frequently upon such affected fruit there is subsequently produced also the blue mold, Penicillium. The blue mold alone, however, does not spread rapidly, and has not the peculiar odor of the brown-rot disease. The disease may appear upon fruit in storage, which seemed to be perfectly colored and sound when passed by the washer.

The fungus. The fungus concerned in the production of this decay is apparently one which was unknown until attention was directed to this lemon disease, and which, while it is an active parasite of citrous fruits, it is doubtless ordinarily a common saprophyte found in moist soils and in water. The mycelium of this

fungus penetrates the rind and other fibrous portions of the lemon to a considerable extent; it is much branched, irregular in diameter, and extensive. Upon the lemon, as a rule, no form of spore is produced, but there is developed frequently a conspicuous aërial growth due to the emergence of many mycelial branches. In some cases these are produced in more or less tuberculate masses. Conidia and sporangia appear under favorable conditions. In moist soil near affected fruit the sporangia are developed abundantly upon a fine much-branched mycelium (Fig. 47). The sporangia measure $20-60 \times 30-90\,\mu$ (averaging $35 \times 50\,\mu$). They are lemon-shaped, or subspherical with pronounced apical protuberance. In water germination is effected by means of a variable number of zoospores, often about thirty, each biciliate with long cilia (Fig. 48).

FIG. 47. SPORANGIA OF PYTHIACYSTIS. (After R. E. Smith)

Control. Ordinarily the fungus does not produce any spore stage upon the surface of the lemon. On moist soil, however, it produces sporangia and sometimes conidia. The infection of the fruit usually takes place in the orchards, and also subsequently by direct contact and also by the operation of washing. It has been found, for instance, that if uninfected lemons are dipped in water in which diseased ones have been washed, infection will in time result on the healthy fruit. In fact, the ordinary wash water may itself contain a large number of germs of this fungus and it may also live more or less permanently in the machine used for washing such fruit. The remedy, therefore, for such conditions is very simple and merely consists in treating the water used for washing purposes with some aseptic or toxic agent. The most practicable method which has been devised consists in using copper sulfate, formalin, or potassium permanganate. In using formalin one part of the reagent to ten thousand parts

FIG. 48. GERMINATING SPORANGIUM OF PYTHIACYSTIS. (After R. E. Smith)

of water may be employed, or 1 pint to 1250 gallons has been sufficient to check the infection. Permanganate of potash is rather a mild disinfectant as compared with formalin and it is necessary to use 1 pound to 625 gallons. A stronger concentration discolors slightly and the former strength is advised. Copper sulfate, which is both a cheap and effective disinfectant, may be used, of about the same strength as the permanganate of potash. Care should be taken that this is not employed in a very much more concentrated form, 1 pound to 250 gallons, for instance, resulting in injury in the form of a burn. Unfortunately, however, this substance attacks the arm of the tank and is therefore less desirable than those previously referred to. A higher concentration of blue stone is needed on account of the alkalinity of the water used. In distilled water, one part of blue stone to one million will be effective.

IX. PERONOSPORALES

De Bary, A. Zur Kenntnis der Peronosporeen. Bot. Zeit. **39**: 521–530, 537–544, 553–563, 569–578, 585–595, 601–609, 617–625. *pl. 5*. 1881.

Farlow, W. G. Enumeration of the Peronosporeæ of the United States. Bot. Gaz. **8**: 305–315, 327–337. 1883.

Lüstner, G. Untersuchungen über die Peronospora-Epidemien der Jahre 1905 und 1906. Ber. d. Königl. Lehranstalt für Wein-, Obst- und Gartenbau, Geisenheim a/Rh. (1906): 119–140.

Rostowzew, S. J. Beiträge zur Kenntnis der Peronosporeen. Flora **92**: 405–430. *pl. 11–13*. 1903.

Schroeter, J. Peronosporineæ. Pflanzenfamilien (Engler u. Prantl) **1** (1* Abt.): 108–119. *figs. 92–102*. 1893.

Swingle, W. T. Some Peronosporaceæ in the Herbarium of the Division of Vegetable Pathology. Journ. Mycol. **7**: 109–130. 1892.

Wilson, G. W. Studies in North American Peronosporales. I. The Genus Albugo. Torrey Bot. Club Bullt. **34**: 61–84. 1907. II. Phytophthoreæ and Rhysotheceæ. Ibid.: 387–416.

The members of this order are entirely parasitic, many of the species causing important diseases of cultivated plants. The mycelium is well developed, siphonaceous, and, with exceptions in one genus (Phytophthora), intercellular. The asexual spores, which may in general be termed conidia, are produced upon erect conidiophores, which are from the first, or which ultimately become, aërial. The conidiophores may be simple or diversely branched. The conidia germinate either by means of a germ tube or by the production of motile spores, zoospores; in the

latter case the conidium becomes a zoosporangium. Oogonia and antheridia are also present, and these are produced within the tissues of the host. The oospores upon germination give rise to numerous zoospores or to a single germ tube. Some members of both families (Albuginaceæ and Peronosporaceæ) of this order deserve careful study. To the genus Phytophthora of the Peronosporaceæ Pythium and Pythiacystis are perhaps closely related.

Albuginaceæ. In this family the conidia are borne in chains; the conidiophores arise in the form of large cushions which might be termed sori. They are developed beneath the epidermis, but the latter is finally ruptured, and the conidia are exposed. The oospore germinates by the production of zoospores. There is one genus, Cystopus.

Peronosporaceæ. The members of this family are distinguished from the preceding largely by the conidiophores, which are from the beginning aërial. The conidia are also produced singly. This is properly the family of the *downy mildews.* The mycelium, which is commonly intercellular, develops either branched or knob-like haustoria. The oospore germinates by means of a germ tube.

The following generic key includes most of the genera together with the salient generic characteristics, and is, in this family, more practical than a description of each genus:

A. Conidiophore fully developed prior to the formation of conidia.
  1. Conidium on germination becoming a swarm sporangium (zoosporangium). Oospore free from the wall of the oogonium. . . . . *Plasmopara*
  2. Conidium becoming a swarm sporangium, conidiophore short, irregular in form and diameter, oospore filling oogonium, with closely adherent walls. . . . . *Sclerospora*
  3. Conidium germinating by means of a germ tube.
    a. Conidium provided with a terminal papilla from which the germ tube proceeds. Fertile tips arising from a disk-like swelling . . . . *Bremia*
    b. Conidium without papilla. Fertile tips ordinarily branch-like . . . . *Peronospora*

B. Conidiophore incomplete when first conidia produced. Fertile tips swelling and continuing growth as successive conidia are formed. *Phytophthora*

X. WHITE "RUST" OF CRUCIFERS

Cystopus candidus (Pers.) Lév.

DAVIS, B. M. The Fertilization of Albugo candida. Bot. Gaz. **29**: 296–310. *pl. 22.* 1900.

WAGER, H. On the Structure and Reproduction of Cystopus candidus Lév. Ann. Bot. **10**: 295–339. *pls. 25, 26.* 1895.

ZALEWSKI, A. Zur Kenntniss der Gattung Cystopus Lév. Bot. Centrbl. **15**: 215–224. 1883.

FIG. 49. FLOWERS AND PEDUNCLES OF RADISH DEFORMED BY CYSTOPUS (Photograph by H. H. Whetzel)

The common white "rust" of cruciferous plants appears to be common throughout the world. The fungus is frequently one of the first of the order to make its appearance in the spring and the last to disappear in winter. Evidently, it is not readily affected by minor climatic differences, and probably slight dews are sufficient to insure its propagation.

This fungus is most common upon the forms of the ubiquitous shepherd's purse (*Capsella Bursa-pastoris*); but it is also common upon the radish (*Raphanus sativus*), horse radish (*Cochlearia Armoracia*), cress (*Brassica oleracea*), turnip (*Brassica Rapa*), mustard (*Brassica nigra*), water cress (*Radicula Nasturtium-aquaticum*), etc.

Symptoms. The effects of the fungus are somewhat various upon the different hosts. Upon the shepherd's purse the stems are enlarged and distorted, while no unusual malformations of floral organs and leaves generally occur. On the radish the floral organs may be strikingly hypertrophied (Fig. 49), ovary sacs greatly enlarged, stamens, petals, and sepals distended and sometimes becoming leaf-like. Upon nearly all hosts the porcelaneous

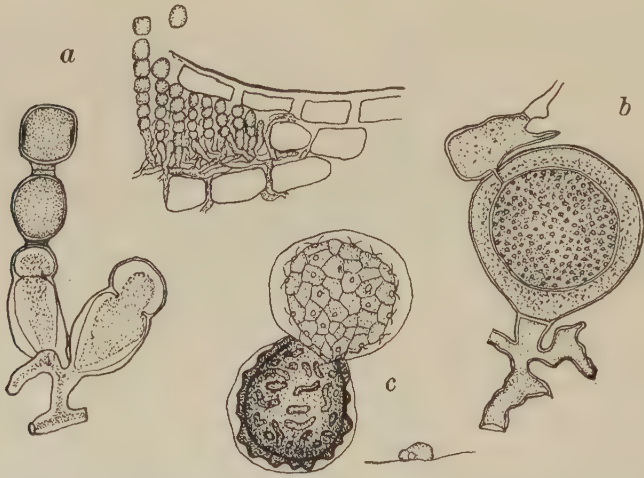


FIG. 50. CONIDIAL STAGE, FERTILIZATION, AND GERMINATING OOSPORE OF CYSTOPUS. (*b* and *c*, after De Bary)

conidial cushions, characteristic of the family to which this species belongs, are prominent.

The fungus. The conidial cushions occur upon leaves, stems, and floral parts, or fruits. On the majority of hosts, such as shepherd's purse, horse radish, etc., oospores generally occur only in the stems, yet upon some other hosts, particularly upon certain mustards in the western United States, oospores alone are common. The mycelium is considerable, and constantly intercellular, with abundant knob-like haustoria. The mycelium develops abundantly at some points just beneath the epidermis, and there are produced numerous short, erect, basally branched conidiophores. The latter give rise to simple chains of spores in basipetal succession. These are usually separated one from another by slight

beak-like projections. The developing cushions break the epidermis and the mature spores are set free. Fig. 50, *a*, shows a section through a conidial cushion. Under favorable conditions germination of the conidia proceeds promptly and each conidium becomes a zoosporangium, the protoplasmic contents dividing into six or more parts which emerge through an opening developed either basally or terminally. The zoospores are set free as ovate swarm cells with two unequal lateral cilia. After a brief motile period they come to rest, become invested with a cell wall, and may push out a germ tube in a few hours.

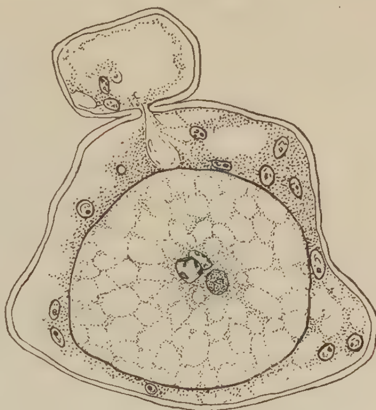


FIG. 51. FERTILIZATION IN CYSTOPUS (After B. M. Davis)

The oospores are normally produced later than the conidia. The oogonia and antheridia develop in the intercellular spaces, and the mode of formation is much as in Pythium. The oogonia are, however, in this case larger, measuring from 50 to 60 μ in diameter. There are numerous nuclei in the early stages. It is generally agreed that in this species the differentiation of the ooplasm is accompanied by a migration of the nuclei to a peripheral position and the organization of a central body termed a cœnocentrum. A nucleus then returns from this nuclear zone to the region of the cœnocentrum. Preceding the latter, however, it is held that one karyokinetic division may be constantly found. The zone of the now disintegrating nuclei indicates fairly well the line of differentiation between periplasm and ooplasm. As the antheridial tube penetrates, a cell wall begins to be laid down between ooplasm and periplasm. Into the tube of the antheridium a single antheridial nucleus migrates.

Special attention is called to the fact that at maturity of the egg there is a single nucleus in each gamete, but the egg is also provided with a cœnocentrum. Fertilization proceeds exactly as in Pythium, and during the nuclear fusion the cœnocentrum promptly disappears. Fig. 51 shows the oosphere with developing

wall, the remains of the antheridium, the fusion nuclei, and the cœnocentrum. The wall of the mature oospore is brown in color and sculptured in a characteristic manner. The oospores are 35–40μ in diameter. It is believed that nuclear division proceeds, during the maturity of the oospores, until about thirty-two nuclei are present, and it has been suggested that each of these divides twice preceding germination, which again takes place by the formation of zoospores. A period of rest is invariably required between maturity and germination.

XI. CYSTOPUS: OTHER SPECIES

Other species of Cystopus which are very generally distributed, occurring on common hosts of the garden and field, are

Cystopus Tragopogonis Pers., found on salsify (*Tragopogon porrifolius*) and various other Compositæ;

Cystopus convolvulacearum Otth., on species of the morning glory and sweet potato family, Convolvulaceæ;

Cystopus Bliti (Biv.) Lév., on several species of pigweed, Amarantaceæ. The oospores of this species are often very abundant in late autumn; the stems and flower spikes in which they occur are deformed and usually purplish.

XII. DOWNY MILDEW OF THE GRAPE

Plasmopara Viticola (B. & C.) Berl. & De Toni

CORNU, M. Études sur les Péronosporées. [Observations sur le Phylloxera et sur les parasitaires de la vigne.] **1**: 101–184. 1881; **2**: 1–91. 1882.

FARLOW, W. G. On the American Grape-Vine Mildew. Bullt. of the Bussey Institution (1876): 415–425. *pls. 2–3.*

Report on Experiments made in 1888 in the Treatment of the Downy Mildew and Black Rot of the Grape Vine. Bot. Div., U. S. Dept. Agl. Bullt. **10**: 1–61. 1889.

SCRIBNER, F. L. The Fungous Diseases of the Grape Vine: I. The Downy Mildew. Bot. Div., U. S. Dept. Agl. Bullt. **2**: 7–18. *pls. 1, 2, 4* (in part). 1886.

VIALA, P. Mildiou. Les maladies de la vigne (Chap. **2**): 57–155. *pls. 2–3. figs. 20–46.* 1893. Montpellier et Paris.

Occurrence. The downy mildew of the grape is one of the most important disease-producing organisms among the Peronosporaceæ. The fungus seems to be of American origin, and

was at first probably more or less confined to the Mississippi Valley and states to the eastward. It has been known for a long time as a pest in the Middle Atlantic States, extending westward to the Mississippi, but in the states farther to the

FIG. 52. GRAPE LEAF WITH EARLY STAGE OF DOWNY MILDEW
(Photograph by H. H. Whetzel)

northeast, while equally common, it has been less disastrous in its effects. This is to be accounted for in part by the vigorous growth of the vine under more constant rainfall; but the greater injury farther west has been attributed particularly to the fact that the fungus appears earlier in the season. The disease was

not known on the Pacific Slope during the early history of grape-growing in that region, but it is now not uncommon. The fungus was apparently introduced into Europe from America, and it became a serious pest within a very short time after it was first noted in that country. This greater injury under European conditions had been predicted by Farlow on account of the early spring and the relatively slight growth which is made by *Vitis vinifera*, the cultivated grape of Europe.

The grape mildew has been found abundantly on practically all species of cultivated or wild grapes, that is, upon such species as *Vitis æstivalis*, *Vitis cordifolia*, *Vitis Labrusca*, and *Vitis vinifera*. It occurs, therefore, on the smooth-leaved species as well as on those possessing a downy lower surface, and there are few varieties which are notably resistant under all conditions.

This fungus attacks practically all young or green portions of the growing vine, — leaves, shoots, and berries. The vine may, therefore, under conditions favorable for the development of the fungus, show the disease abundantly. Under ordinary conditions, however, it is largely confined to the leaves, and its injurious action consists in the production of discolored spots which prevent or inhibit normal physiological activities (Fig. 52). A slight attack of this fungus may, however, cause no perceptible diminution of the amount of the grape crop. Under ordinary circumstances the fungus may be found in the early summer, particularly if the season is moist, and it may reach its greatest intensity during August or as late as September.

Symptoms. Upon the leaves the first indications of the disease are indefinite spots, which from the upper surface are yellowish in color and irregular in size and form. Upon the lower surface of the leaf the spots are not so evident, but almost simultaneously with the spots above, the sporophores of the fungus are produced on the lower surface. Later in the season the spots may turn brownish above, and upon some varieties of grapes they may be almost brown from the beginning, finally appearing as small, angular brown spots, visible on both surfaces of the leaf. It is only when the fungus is very severe that the leaf dries and falls prematurely. Upon the shoots depressed areas, dark in color, are produced, and these therefore bear no resemblance to anthracnose,

which may appear upon the shoots, as subsequently described. Commonly the fungus is found upon the berries only when the latter are young, although a form of brown rot, sometimes called gray rot, may be produced by this fungus when the berry is more

FIG. 53. PLASMOPARA ON GRAPE. (*b* and *d* after Farlow)
a, mycelium; *b*, mature conidiophore; *c* and *d*, zoospore and oospore formation, respectively

than two-thirds grown (see illustration facing page 1). Upon *Vitis cordifolia* the fungus may fruit so abundantly upon the young berries as to completely envelop them in a downy mass of sporophores. Under such circumstances the berry does not at that stage show evidences of decay, and it is only when the berries are older, and in other species nearly full grown, that the fungus produces a true decay. When the disease occurs upon the young fruits the financial losses may be severe.

The fungus. The mycelium is abundant in the intercellular spaces, varying in diameter from 8 to 12 μ, but frequently it is of less diameter in the more compact tissue of *Vitis vinifera*. In the leaves the fungous hyphæ may be found throughout the part affected, except in the woody parts of the bundles of the veins and in the stem. They occur also in all tissues except the xylem. The haustoria are of the characteristic knob shape. The hyphæ are somewhat more densely assembled in the vicinity of the stomata, and through the stomata there emerge several sporophores (Fig. 53), each becoming constricted in its passage through the opening, but subsequently attaining practically normal or more than normal diameter, therefore often showing a bulbous base. At maturity they are irregularly branched, the central axis giving rise to lateral offshoots and sometimes the axis itself may be lost, due to the preponderance in growth of the branches. The method of branching and sporangial production has been carefully worked out by Farlow, according to whom "the branches, which are few in number, generally from four to eight, are placed alternately on the upper third of the axis, being generally, but not always, distichously arranged. Relatively to the main axis, they are all short, the broadest expansion from side to side not being usually greater than .12 mm. The branches are furnished with branchlets of a second and third order" (Fig. 53, *b*).

In this species germination of the zoosporangia takes place in water in about one and one quarter hours. The process, as summarized from Farlow's careful studies of this phenomenon, is about as follows: Spores produced during the night and put to germinate during the early morning on slides containing a few drops of water show first at the end of an hour the beginning of segmentation of the protoplasmic contents, each segment having a single nucleus. These round themselves off into oval bodies, which are massed at the distal end of the sporangium, and in time they escape by dissolving or rupturing the cell wall. The zoospores pass out, generally one at a time, remain quiescent a moment in becoming free, and then swim off rapidly, each as a mature zoospore, provided with two lateral cilia, projecting usually anteriorly and posteriorly (Fig. 53, *c*). In general, the zoospores are more or less ovate, but the form in the

same zoospore may undergo considerable change. The period of activity is, as a rule, from fifteen to twenty minutes, at the end of which time the resting condition is assumed by the loss of cilia, by becoming spherical, and by the development of a cell wall; then follows germination by means of a germ tube. Germination is effected practically irrespective of ordinary conditions of light and temperature.

The oospores of this species are not so commonly found as the conidiophores. They are more common, apparently, in the northeastern states and are generally found upon *Vitis æstivalis*. They are commonly present during late September and always "in the discolored, shriveled parts of the leaves, and are most abundant just inside what are called the palisade cells of the upper surface." The formation of these oospores is characteristic of the family; that is, large terminal or intercalary swellings of the mycelium are cut off by septa, and there results an oogonium. In the neighborhood of this oogonium there may be produced one or more smaller antheridia. The subsequent development of these two structures, the fusion phenomena, and the development of the oospores (Fig. 53, *d*) take place approximately as described for *Pythium de Baryanum* and *Cystopus candidus*. At maturity the oospore almost completely fills the original oogonium wall, and the wall of the oospore itself is comparatively smooth, thick, and yellowish. The oospores measure about 30 μ in diameter. For the study of the oospores dried material may be teased out in potassium hydrate solution, or it may be necessary to boil the material in this solution, afterward neutralizing with hydrochloric acid. The oospores are set free by the disintegration of the tissues of the leaf, and they are probably important in carrying the fungus over winter. Nevertheless, much work needs to be done in the way of determining to what extent the oospores are necessary in the annual propagation of this species.

Control measures. In the control of this fungus Bordeaux mixture is most effective, and it is only during very moist seasons, that is, where it is difficult to keep the surfaces of the leaves covered with the preparation, that the fungus has been able to gain headway in spite of spraying operations. In this connection it is interesting to note that copper fungicidal

mixtures first came into use in the treatment of downy mildew of the grape. The experiments of Millardet in France in 1881, and subsequently, led promptly to the perfection of Bordeaux mixture as a fungicide.

XIII. DOWNY MILDEW OF THE CUCUMBER

Plasmopara cubensis (B. & C.) Humphrey

CLINTON, G. P. Downy Mildew, or Blight, Peronoplasmopara cubensis (B. & C.) Clint., of Musk Melons and Cucumbers. Conn. (New Haven) Agl. Exp. Sta. Rept.: 329–362. *pls. 29–31.* 1904.
FARLOW, W. G. Notes on Fungi I. Bot. Gaz. **14**: 187–190. 1889.
HUMPHREY, J. E. The Cucumber Mildew. — Plasmopara Cubensis (B. & C.) Mass. Agl. Exp. Sta. Rept. **8**: 210–212. 1890.
SIRRINE, F. A., and STEWART, F. C. Spraying Cucumbers in the Season of 1898. N. Y. Agl. Exp. Sta. Bullt. **156**: 376–396. *pls. 1–4.* 1898.
STEWART, F. C. The Downy Mildew of the Cucumber: What it is and how to prevent it. N. Y. Agl. Exp. Sta. Bullt. **119**: 154–183. *pls. 1–4.* 1897.

Habitat relations. The two most important diseases of the cucumber, or indeed of the commonly cultivated members of the gourd family in this country, are the downy mildew and the bacterial wilt disease. It has been definitely ascertained that the Plasmopara is the chief cause of the poor crops which have prevailed in the cucumber districts of New York and a part of New Jersey in recent years. The downy mildew of the cucumber has an interesting though brief economic history. In 1869 the fungus was described upon a wild plant found in Cuba. It appears that this fungus was not again reported until early in the spring of 1889, when it was found in greenhouses in New Jersey,[1] and by the end of the season it had been detected upon the cucumber, squash, and pumpkin in the field in several locations in that state. It was further reported during the same season from several southern states. Subsequently it developed [2] that the fungus had been found in Japan early in the same year.

This disease-producing organism is now known to occur in many sections of the eastern and southern United States, but no mention of its occurrence in Europe has as yet come to my attention. It is most abundant in regions which have long

[1] Halsted, B. D. Peronospora on Cucumbers. Bot. Gaz. **14**: 149–150. 1889.
[2] Farlow. Notes on Fungi, *l. c.*

been devoted to the cultivation of melons or of cucumbers, especially for the pickling trade. Nevertheless, it is now a very constant disease in greenhouse-grown cucumbers.

The fungus has been found on most of the cultivated species of the Cucurbitaceæ, or gourd family, such as cucumbers, muskmelons or watermelons, squash, pumpkins, gherkin, and also upon the star cucumber, *Sicyos angulatus*, and a few other wild species.

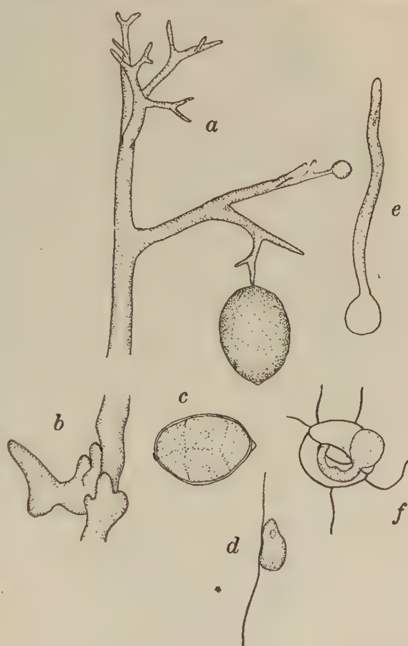


FIG. 54. PLASMOPARA ON CUCUMBER. SALIENT PHASES OF CONIDIAL CYCLE (After G. P. Clinton)

Symptoms and effects of the disease. The effect of this disease upon the host, that is, upon the cucumber, have been very clearly presented by Stewart as follows :

The leaves show yellow spots which have no definite outline. If the weather is warm and favorable for the disease, these spots enlarge rapidly and run together so that the whole leaf becomes yellow and soon dies and shrivels like a leaf killed by frost. If the weather is cool, the yellow spots spread less rapidly. In the latter case the central portion of the yellow spots becomes dead and brittle and of a light-brown color. . . . The disease invariably begins with the oldest leaves and proceeds toward the tips of the vines. Hence the disease appears to proceed from the center of a hill outward. In a field recently attacked, the center of every hill will be clearly marked by a cluster of yellow leaves, so that the rows may be plainly seen clear across the field, even though the plants are large and cover the ground. Affected plants continue to grow at the tips and put out new leaves, and it is interesting to note how the disease follows at a distance of about four or five leaves behind the growing tip. After the disease is once thoroughly established, very few cucumbers are produced, although the plants may continue to flower profusely. The few cucumbers which are formed grow slowly and become misshapen so that they are unsaleable. . . . Of the total shortage of 75 per cent. in the Long Island cucumber crop of 1896, it is safe to say that 55 per cent. was due to the downy mildew.

The fungus. The mycelium of this fungus is typical of the family. The haustoria have very much the form of those previously described for the grape mycelium. The sporophores arise through the stomates, singly or in small clusters, and they are considerably branched, somewhat more flexuous than those of the grape mildew, and the fruiting tips are less rigid and more widely separated one from another, corresponding more nearly to separate branches. The spores or zoosporangia are slightly violet tinted in mass and generally ovate in outline. The germination of the spore has been followed carefully and is known to take place by means of the characteristic motile zoospores. Clinton alone has illustrated the various stages of germination (Fig. 54, *c* and *d*). Occasionally the normal sporophores are accompanied by short, swollen hyphæ (Fig. 54, *b*), which may also bear spores. It is believed that the latter are produced under unfavorable conditions, and similar modifications have been noted in other species. The oosporic form of this species has not yet been found, and it is doubtful if it occurs in this country.

Fig. 55. Peronospora on Young Cabbage Leaf

Control. Very careful experiments have been made with a view to holding in check the ravages of this fungus, and it has been found that the greater part of the damage can be prevented by

properly spraying with Bordeaux mixture. Seven sprayings in New York have almost invariably enabled growers to control this disease. The 5–5–50 formula may be recommended.

Plasmopara Halstedii Farl. is widely distributed in the United States, where it is found on various members of the Compositæ, especially sunflower and Jerusalem artichoke, *Helianthus annuus* and *Helianthus tuberosus*, species of Bidens, etc.

XIV. SCLEROSPORA

CUGINI, G., and TRAVERSO, G. B. La Sclerospora macrospora Sacc. parasita della Zea Mays. Le Stazioni speriment. agrar. italiane. **35**: 46–49.

TRAVERSO, G. B. Note critiche sopra la Sclerospora parassite di Graminacee. Malpighia. **16**: 280–290. 1902.

There are perhaps three species of this genus. The species which has been apparently most widely distributed and best known is *Sclerospora graminicola* (Sacc.) Schroet. This species occurs upon several grasses, especially Setaria spp. The leaves are affected, and in severe attacks they may be considerably rolled and shredded. The conidiophores are relatively evanescent. They are irregular in form and generally nodulose, or of irregular diameter, generally short, branched, and slightly colored with conidia $12-20 \times 10-18\,\mu$. The oospores are at first densely granular and hyaline in appearance, later they are slightly colored, thick-walled, united with wall of oogonium, and angularly globoidal, usually $40-42\,\mu$ in diameter. Another important species, *Sclerospora macrospora* Sacc., formerly known only on a few true grasses, has more recently been found to be the cause of an important disease of corn in Italy. The tassel is the chief seat of infection. Fairchild reports this fungus from the United States. In this species conidiophores are unknown, and the oospores are about $60-65\,\mu$ in diameter.

XV. DOWNY MILDEW OF CRUCIFERS

Peronospora parasitica (Pers.) De Bary

WAGER, HAROLD. On the Fertilization of Peronospora parasitica. Ann. Bot. **14**: 263–279. *pl. 26.* 1900.

This fungus seems to be particularly abundant in England, but it is also found in other parts of Europe and in the United States. Practically all cultivated Cruciferæ are more or less subject to it,

as well as many wild species. It frequently causes stem deformities, and in England it is often associated with *Cystopus candidus* on Capsella, while in this country it is perhaps best known as a pest in cauliflower culture under glass, yet occasionally destructive in cabbage cultures in the open, and less frequently occurring on radish, turnip, etc.

FIG. 56. PERONOSPORA ON CABBAGE: CONIDIAL STAGE

The conidiophores, shown in Fig. 56, *a*, are characteristic of the genus. The conidia germinate (Fig. 56, *b*) from one side by means of a germ tube. The development of the oospores of this species has been carefully studied and would correspond closely to that described for *Cystopus candidus* except that in this Peronospora there is no true cœnocentrum.

XVI. ONION MILDEW

Peronospora Schleideniana De Bary

THAXTER, R. The Onion Mildew. Conn. Agl. Exp. Sta. Rept. (1889): 155–158.
TRELEASE, WM. The Onion Mold. Wis. Agl. Exp. Sta. Rept. (1884): 38–44.
WHETZEL, H. H. Onion Blight. Cornell Agl. Exp. Sta. Bullt. **218**: 138–161. *figs. 1–17.* 1904.

The onion mildew, blight, or mold is a disease which has been recognized for more than half a century. At various times since 1884 it has been reported as of consequence in parts of the United States from New England to Wisconsin. It is probably far more common and destructive than has been supposed, as shown by the observations of Whetzel in 1903.

The disease, in the regions referred to, appears in late June or July, and in the early morning while covered with dew it is in young stages conspicuous by a "furry violet appearance" of the affected leaves. Later the leaves become moldy in character, pale, collapsed, and often broken. Fig. 57 shows a diseased plant in

an acute stage. Older onions are apparently more susceptible than young, and recovery in the former case is seldom.

The fungus. The mycelium is considerable, and it penetrates practically all parts of the leaf. The minute haustoria are numerous,

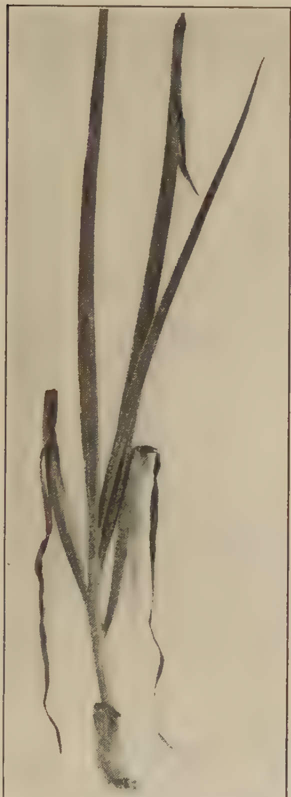


FIG. 57. ONION MILDEW (Photograph by H. H. Whetzel)

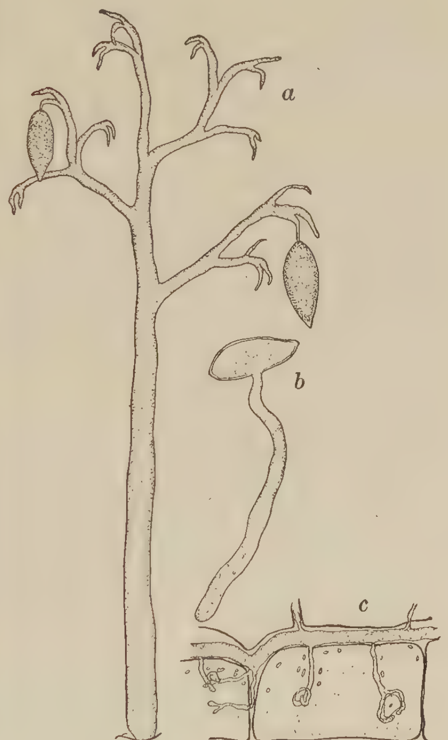


FIG. 58. MATURE CONIDIOPHORE, GERMINATING CONIDIUM, AND MYCELIUM OF ONION PERONOSPORA. (*c* after Whetzel)

thread-like, and often branched at the tip. The conidiophores arise through the stomates. They are of the characteristic type, often 320 μ in height, and bear large elliptical conidia (44–52 × 22–26 μ) which germinate promptly by a side tube and effect penetration through the stomates. The time required for infection and the production of conidiophores again is extremely

short, so that the fungus spreads with great rapidity. Oospores are commonly produced.

Control. It would seem that this fungus has been controlled in New York by systematically spraying where it is likely to be abundant after June 15. In addition, however, it is important to destroy the tops of diseased plants, and by no means to return these to the land or throw them on the compost heap, since the oospores retain their vitality a long time. Rotation of crops is also important.

XVII. PERONOSPORA: OTHER SPECIES

Peronospora sparsa Berk. is not an uncommon parasite of cultivated roses in Europe. At times it has been productive of serious epidemics. Affected leaves show brown spots on the upper surfaces not unlike the blotches produced by other fungi, but on the under surfaces the repeatedly dichotomous conidiophores appear in sufficient quantity to be readily recognized as a mildew.

Peronospora effusa (Grev.) Rabh. develops during moist weather a destructive disease of spinach (*Spinacia oleracea*), and it is also common upon other members of the Chenopodiaceæ, as well as upon certain Plantaginaceæ. Pale or water-soaked spots are produced and the leaves may be rapidly killed. Ordinarily oospores are found in quantity.

XVIII. DOWNY MILDEW OF THE LETTUCE

Bremia Lactucæ Reg.

Downy mildew of the lettuce is not an infrequent pest where lettuce is grown under glass during the winter and spring. It also occurs with cool weather in the open, particularly upon fall lettuce. This fungus is also quite generally distributed on several species of Senecio, Sonchus, and Lactuca as well as on a few other species of Compositæ. Upon lettuce the conidiophores of the fungus appear on the under side of the leaf, and the areas affected are at first merely paler in color, afterwards wilting.

The conidiophores appear singly. They are much branched and near the apices of the branches at maturity peculiar disk-like swellings are produced, each of which originates circumferentially about four tentacular tips inclined outward so as to continue more or less the general direction of the branch axis. Ovate conidia measuring $16–22 \times 15–20\,\mu$ are produced singly, and these germinate readily in water, emitting a germ tube through an apically developed pore (Fig. 59). Oospores are occasionally found. These are small, $26–35\,\mu$ in diameter, light brown, and roughened. In controlling this fungus general sanitary precautions must be taken and a maximum of light and ventilation should be constantly afforded.

FIG. 59. GERMINATING CONIDIUM OF BREMIA

XIX. THE LATE BLIGHT AND ROT OF THE POTATO

Phytophthora infestans (Mont.) De Bary

CLINTON, G. P. Downy Mildew, or Blight, Phytophthora infestans (Mont.) De By., of Potatoes. Conn. (New Haven) Agl. Exp. Sta. Rept. (1904): 363–384. *pls. 32–37.* Ibid. (1905): 304–330. *pls. 23–25.*

DE BARY, A. Recherches sur le développement de quelques champignons parasites. Ann. d. Sci. Nat. Bot. **20** (4me Sér.): 1–148. *pls. 1–13.* 1876.

DE BARY, A. Researches into the Nature of the Potato Fungus — *Phytophthora infestans.* Journ. Roy. Agl. Soc. **12** (2d ser.): 240–269. *figs. 1–8.* 1876.

JONES, L. R. Certain Potato Diseases and their Remedies. Vt. Agl. Exp. Sta. Bullt. **72**: 13–16.

(Short accounts also in several earlier bulletins and reports.)

JONES, L. R. Disease Resistance of Potatoes. Bureau Plant Ind., U. S. Dept. Agl. Bullt. **87**: 1–39. 1905.

STEWART, F. C., EUSTACE, H. J., and SIRRINE, F. A. Potato Spraying Experiments in 1906. N. Y. Agl. Exp. Sta. Bullt. **279**: 154–229. *pls. 1–2. figs. 1–4.* 1906. (Cf., also, Bullts. **290**, **307**, and **311**.)

STUART, WM. Disease Resistance of Potatoes. Vt. Agl. Exp. Sta. Bullt. **122**: 107–136. 1906.

WARD, H. MARSHALL. Diseases of Plants. The "Potato Disease," Chapt. **5**: 59–85. 1896. London.

The late blight and rot of the potato is so generally known that frequently this malady is simply called the "potato disease." From an economic point of view it is the oldest potato malady,

and it has been the cause of great disaster in many potato-growing regions before methods for its control were well known. All who are familiar with the history of potato growing doubtless know of the potato famine of 1845. The serious famine in Ireland was very largely due to this failure of the potato crop, a failure due to the prevalence and unusual destructiveness of the Phytophthora.

FIG. 60. PHYTOPHTHORA ON POTATO LEAVES. (Photograph by F. C. Stewart)

Distribution. At one time it was the current opinion that this fungus is very widely distributed throughout the United States, but a more careful study of potato diseases has shown that it is very largely limited to New England and New York, extending also into the potato-growing regions of Canada. It is not entirely absent from regions much farther south and west, but in such districts it seldom assumes any importance. In Europe it is widely distributed and may be disastrous throughout Great Britain, as well as east and west from Russia to France, extending even as far south as Italy. The distribution of this fungus and its importance as a disease organism are entirely dependent upon climatic conditions. It has been shown that it becomes of serious importance only when favored by warm, moist weather. As a rule, the fungus does not appear in the northeastern United States prior to the last days of July, and it is most abundant during August and early September. A few days of rainy weather suffice to give it a start and to bring to fruiting the conidial stage on the leaves. The distribution of the fungus is then accomplished with alarming rapidity, and whole fields may be devastated within a period covering only a few days of such weather. While it is generally stated that warm weather

is required, it has also been shown that the high temperature of summer quickly checks its spread.

Symptoms. Upon the leaves of the potato this fungus develops characteristic spots which cannot be easily confused with other potato diseases. These spots frequently begin at the edge or tip and spread until the whole leaf may be involved. They present in moist weather a dark, somewhat water-soaked appearance with slightly purplish tint (Fig. 60). In drier weather they are brown without the definite markings of the early blight. The moist appearance of the spots accompanied by the wilting of the leaf, or of that portion affected, offers an easy diagnosis. Generally there is no accompanying stem injury, but in some cases the trouble may extend to the stem; or, again, it may be found upon the leaves as an extension of a stem affection. Upon the tubers this fungus develops the well-known dry rot (Fig. 61). On account of the presence of the mycelium within the tissues of the tuber the cells are killed and the tubers rendered liable to the ordinary forms of wet rot induced by bacterial action or by mold fungi. The dry rot may cause serious damage in the field, yet this damage may be further emphasized or even first made evident while the potatoes are in storage. In regions which are favorable no fungous disease may become more quickly disastrous, particularly when it affects the tubers as well as the vines. Fortunately it is now feasible to prevent the disease and possible even to stamp it out.

FIG. 61. THE PHYTOPHTHORA DISEASE OF POTATO TUBERS. (Photograph by F. C. Stewart)

Host resistance. For more than half a century the resistance of varieties of potatoes to the late blight has received the

attention of scientists. The early work was remarkable for its time, but the actual results accomplished lose their value now on account of the fact that the older varieties have largely disappeared from cultivation. Excellent work was done during the early part of 1870–1880, when Charles Darwin himself became much interested in resistance breeding, 1872–1878. As a result of the interest which was then established, the various wild species of potato growing in South America were carefully studied with reference to this point and numerous crosses and selections made. Again, during the past ten years there has been a revival of interest in this subject, and to-day the general problem is better understood and the results will probably be more lasting. It may be said, however, that while many varieties have been developed which show a considerable degree of resistance, yet it is also true that no variety may be expected to maintain such resistance throughout a long period of time. Gradually there will be deviation from the original sort, and, moreover, its relation to the particular environments in which grown will doubtless also affect the relations to the blight organism.

It cannot be expected that a single variety will be equally resistant under different conditions. Therefore, in diverse localities and particularly in different regions variations will be apparent. The studies which have thus far been made upon resistance have concerned both foliage and tuber resistance. According to the experiments in Vermont (Stuart) Rust Proof was most resistant in 1903, so far as the foliage is concerned, and the Dakota Red was second; while in 1904 the order was as follows: Monterey, *Solanum Commersonii*, *Solanum polyadenium*, Rust Proof, Sutton's Discovery, June, Mexican, Mammoth Gem, and Manum's No. 3. With relation to tuber resistance Dakota Red has made the best showing for two seasons, although it was not wholly free from rot. The other varieties which show least blighting of the foliage were also resistant to the rot. The following interesting summary has been drawn:

1. Some varieties are less subject to vine injury than others.
2. Some show a greater tuber resistance to rot than others.
3. With some there seems to be a fairly close relation between resistance of vine to disease and of the tuber to rot.

4. Selection has not given visible increase of resistance.

5. Hybridization and the growing of seedling plants, followed by careful selection, seem to offer a more logical method of securing disease-resistant varieties than does selection.

The tomato is occasionally subject to this disease, but so far as is now known it is not seriously affected in any part of the world.

The fungus. The mycelium of the Phytophthora, like that of the other members of this family, is unicellular, and the haustoria are filamentous. The conidiophores arise singly or in groups of from two to four from the stomates. The conidiophore is branched, and at the tip of each branch a conidium is produced. The conidium is pushed to one side and the branch continues. The continuation is, however, larger than the tip which produced the conidium, so that this further growth is marked by an enlargement of the branch, making a very characteristic form of conidiophore (Fig. 62). The conidia are ovate and usually measure 27–30 × 15–20 μ. The conidia germinate readily when fresh, by the production of about eight zoospores. Germination may be secured in water but apparently not in nutrient solutions. The zoospores are motile for a brief time, perhaps seldom longer than a hour. They then come to rest and appear spherical and invested with a wall. Germination readily follows, and the germ tube penetrates the leaf either by stomates or by boring through the cuticle. The conidia serve not only to spread the disease rapidly from leaf to leaf, but they also fall upon the soil and may

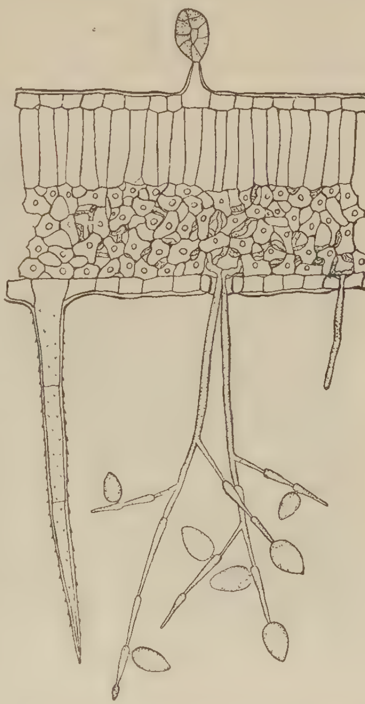


FIG. 62. SECTION OF POTATO LEAF AND CONIDIOPHORES OF THE PHYTOPHTHORA

be brought in contact with tubers. They penetrate the tubers as readily as the leaves, the dry rot being produced in consequence. An affected tuber which does not show the disease in severe form may be used as seed, and thus the disease may be propagated from year to year through the seed tubers. It is now quite certain that the perennial appearance of the disease is due to this use of diseased tubers. It is not always possible, however, to determine if the mycelium is present in the tubers, since, even though they may have been stored for many months, the

FIG. 63. CONTROL OF LATE BLIGHT OF POTATOES BY BORDEAUX MIXTURE
(Photograph by F. C. Stewart)

fungus will not develop further if the conditions are unfavorable. Thus if stored at a low temperature and in a dry atmosphere the rot fungus may not become evident. No oosporic stage of the Phytophthora has been found in the host, but recently Clinton (Conn. Agl. Exp. Sta. Report, 1909-1910) has obtained mature oospores in cultures of the fungus on oat-juice agar.

Control. Studies looking toward the prevention of the potato blight were begun during the middle of the past century. At first the greatest success was accomplished only in securing

comparatively resistant sorts. Soon after the discovery of Bordeaux mixture, and more than thirty years ago, this fungicide was effectively used as a preventive of the late blight. By repeated experiments under a variety of conditions it has now been abundantly shown that the proper use of Bordeaux mixture will, in ordinary seasons, hold this disease in check, reducing its ravages to a small minimum (compare Fig. 63). It is ordinarily advisable to begin spraying with 5–5–50 Bordeaux when the plants are about six inches high, and at least three thorough applications from ten days to two weeks apart are advised. In some cases two additional applications may be necessary. Again, it should be remembered that the fungus is carried over winter largely, or perhaps entirely, by a hibernating mycelium in the tubers, and that every effort should be used to secure seed potatoes from a field in which no blight or rot has occurred. If this latter could be done in connection with a system of rotation, there is no apparent reason why the disease might not be practically stamped out in any considerable region.

XX. DOWNY MILDEW OF LIMA BEANS

Phytophthora Phaseoli Thaxt.

CLINTON, G. P. Downy Mildew, *Phytophthora Phaseoli* Thaxt., of Lima Beans. Conn. Agl. Exp. Sta. Rept. (1905): 278–303. *pls. 20–22.*

HALSTED, B. D. The Downy Mildew of Lima Beans. N. J. Agl. Exp. Sta. Bullt. **151**: 18–24. *figs. 6–9.* 1901.

STURGIS, W. C. The Mildew of Lima Beans (Phytophthora Phaseoli Thaxt.). Conn. Agl. Exp. Sta. Rept. (1897): 159–166. (Also Bot. Gaz. **25**: 191–194. 1898.)

THAXTER, R. Mildew of Lima Beans (Phytophthora Phaseoli Thaxt.). Conn. Agl. Exp. Sta. Rept. (1889): 167–171.

Occurrence. Since the discovery of this fungus, in 1889, near New Haven, Conn., it has been, nearly every year, of sufficient importance to merit special attention in some one or more of the North Atlantic States, and it is also reported from Russia. It is found upon dwarf and pole sorts of the lima bean, *Phaseolus lunatus*, and has been reported on no other host. The fungus is more commonly observed upon the pods, but it also attacks buds, leaves, and shoots. Upon the pods conspicuous patches of the white conidiophores are produced, mostly on the side least protected

by the vine. Pods badly affected may wilt and die, and the fungus may penetrate to the seed.

Moist seasons are most favorable to the production and spread of this disease. Sturgis has determined an interesting relation of this fungus to insects. Bees and other insects visiting the blossoms of the beans may come in contact with the basal portion of the style and the basal portion of the ovary, corresponding to the two ends of the pod. Observation indicates that it is at these points primarily that the fungus begins its work. Rain is also effective in rapidly spreading the spores.

The fungus. The mycelium is irregular in diameter, siphonaceous when young, and often empty and septate when old. The conidiophores are produced in great numbers. They are upright, considerably branched near the bases and longer than those of other species of the genus. They form on the surface a matted mass, and it is possible that threads of the mycelium proper may also develop superficially. The conidia, produced much as in the previous species, are large, measuring generally $28–42 \times 17–27\ \mu$, with a distinct germinal papilla. Fresh spores germinate readily, and generally by the production of biciliate, fusiform zoospores. Germination may also occasionally proceed by means of a germ tube.

Oospores of this fungus were not found until 1905. According to Clinton, "Judging from the experience of the past year, the oospores should be looked for toward the end of the season and in the *seeds* of the pods badly infected with the mildew." It is believed that the production of oospores is frequently interfered with by the rapid growth of saprophytic fungi. The oogonia are inter- or intra-cellular, rather thick-walled, smooth, and generally $19.5–22.5\ \mu$ in diameter.

By carefully removing the seeds from infected pods, Clinton was able to grow this fungus in pure cultures on such seeds, and likewise on nutrient media containing agar, corn meal, etc. Both conidia and oogonia were produced.

Control. On a small scale spraying experiments with Bordeaux mixture have been successful. It is important, however, that only seed from clean pods should be used. Rotation of crops is required wherever oospores are produced, and under such circumstances, also, the destruction of all diseased parts is equally valuable.

Phytophthora cactorum (Leb. & Cohn) Schroet. This species of Phytophthora, if it is a single species, shows as great a range of host plants as the common damping-off fungus, *Pythium de Baryanum*. It was first described as a disease of certain Cactaceæ grown under greenhouse conditions, also of succulent species belonging to the genus Sempervivum. Hartig[1] and other forest botanists have found it to be one of the most disastrous fungi known upon seedlings of such trees as the pine (Pinus), beech (Fagus), and many others. Additional hosts among herbaceous plants have also been well established, and the fungus may be regarded as unusually widespread and important. The conidia (zoosporangia) are unusually large, often averaging 60 μ in diameter. Upon germination numerous zoospores are produced. Oospores are present in this species. These are small, often 24–30 μ.

[1] Hartig, R. Der Buchenkeimlingspilz, Phytophthora Fagi, m. Unters. a d forstbot. Institut, München. **1** : 33–57. *pl. 3.* 1880.

CHAPTER XI

ASCOMYCETES

The Ascomycetes, the largest class of the fungi, containing approximately half of all the described species, have perhaps one common characteristic, — the ascus, or spore sac, generally with a definite number of spores (ordinarily eight). The ascus is of many types and may be produced in a variety of ways, sometimes apparently in a manner analogous to simple sporangia; again, it may be formed upon the surface of, or within, more or less complex fruit bodies. The fruit bodies, in turn, may be within or upon a modified mycelial tissue, termed a stroma. In some cases the fruit body and asci are developed after cell and nuclear fusion in special organs, phenomena indicating sexuality. The size, form, and consistency of the fruit bodies are extremely diverse, examples of these diversities being well borne in mind by a comparison of the large edible morel with the minute fruit bodies (perithecia) of the lilac mildew.

Nonsexual, or conidial, spore forms of manifold variety are known, and a single species may possess several of these forms. In general, the mycelium is considerable, exposed or imbedded in the substratum, septate, and relatively thick-walled. Some orders contain only a few and others many parasitic species.

As usually considered, the Ascomycetes include about ten orders and more than sixty families. For convenience, two subdivisions, with rather artificial limitations, may be recognized in this class among those with definite fruit bodies, namely, (1) the Discomycetes, in which the asci are produced in a body finally opening more or less as a cup-shaped or saucer-shaped apothecium; and (2) the Pyrenomycetes, in which the asci are developed within a perithecium, or an enveloping structure, which may be entirely closed, or open by a relatively small mouth, the ostiolum.

The families of the Discomycetes (or discomycete-like forms) which are here of interest are Exoascaceæ, Helotiaceæ, Mollisiaceæ, and Phacidiaceæ. The Pyrenomycetes from which important parasitic representatives have been selected are the Perisporiaceæ, Erysiphaceæ, Hypocreaceæ, Dothidiaceæ, Mycospherellaceæ, Pleosporaceæ, Gnomoniaceæ, and Diatrypaceæ.

I. EXOASCACEÆ

ATKINSON, G. F. Leaf Curl and Plum Pockets. Cornell Univ. Agl. Exp. Sta. Bullt. **73**: 319–355. *pls. 1–20.* 1894.

PATTERSON, FLORA W. A Study of North Am. Parasitic Exoasceæ. Labs. Natural Hist., Univ. of Iowa Bullt. **3**: 89–135. *pls. 1–4.* 1895.

RATHAY, E. Ueber die Hexenbesen der Kirschbäume und über *Exoascus Wiesneri n. sp.* Sitzber. d. kaisl. Akademie d. Wiss. **83**: 267–288. *pls. 1, 2.* 1881.

ROBINSON, B. L. Notes on the Genus Taphrina. Ann. Bot. **1**: 163–176. 1887.

SADEBECK, R. Die parasitischen Exoasceen. Eine Monographie (Arb. d. bot. Museums zu Hamburg). 1893.

SADEBECK, R. Einige neue Beobachtungen und kritische Bemerkungen über d. Exoascaceæ. Ber. d. deut. bot. Ges. **13**: 265–280. *pl. 21.* 1895.

SCHROETER, J. Exoascaceæ. Pflanzenfamilien (Engler u. Prantl) **1** (1* Abt.): 158–161. *fig. 136.* 1894.

The Exoascaceæ are parasitic fungi causing slight or very marked abnormalities of the leaves, fruits, etc., of a variety of plants, mostly woody forms. The deformities are commonly of the nature of leaf curls, malformed fruits (such as plum pockets), and witches' brooms. Such diseases are especially common among the stone fruits. This family of fungi is considered by many to be closely related to the lowest Discomycetes. In the Exoascaceæ, however, the asci are produced on the surface of the host, arising directly from the mycelium, without the development of a distinct, complex, basal structure, or hymenial layer. Each ascus may possess a stalk cell or it may be merely cut off by a cross wall from a hypha growing perpendicular to the surface. An ascus usually contains eight spores, which in some cases bud extensively in a yeast-like manner, even within the ascus.

In the genus Exoascus, which embraces those forms of greatest economic importance in the family, there are almost constantly eight spores, and budding seldom occurs prior to the expulsion of the spores from the ascus.

II. PEACH LEAF CURL

Exoascus deformans (Berk.) Fuckel

Duggar, B. M. Peach Leaf Curl. Cornell Agl. Exp. Sta. Bullt. **164**: 371–388. *figs. 66–72.* 1899.

Pierce, N. B. Peach Leaf Curl: Its Nature and Treatment. Div. Veg. Path. and Phys., U. S. Dept. Agl. Bullt. **20**: 1–204. *pls. 1–30.* 1900.

Selby, A. D. Preliminary Report upon Diseases of the Peach. Ohio Agl. Exp. Sta. Bullt. **92**: 226–231. 1898.

Selby, A. D. Variation in the Amount of Leaf Curl of the Peach (Exoascus deformans) in the Light of Weather Conditions. Proc. Assoc. Prom. Agl. Sci., Ann. Meeting **20**: 98–104. 1899.

Peach leaf curl (*Kräuselkrankheit* in Germany; *Cloque du pecher* in France) is an important fungous disease affecting particularly the leaves and tender shoots of the peach, but injuring likewise, occasionally, the flowers and fruit.

Distribution. Attempts to determine the country which might be regarded as the original home of this fungus have proved wholly futile. Leaf curl is now a more or less common disease in nearly all peach-growing regions of the world. In North America it is known throughout the country, at least east and west, and from northern Canada to the Gulf of Mexico; while in South America it has also been reported from several peach-growing districts. In Europe it has long been common, having been reported in England as early as 1821, and it is disastrous in many sections of China and Japan. This disease occurs also in southern Africa, and from the Sahara northward in Algeria. According to reports it prevailed in Australia even in 1856, and it has proved most pernicious to peach-growing interests in New Zealand. In general, therefore, this disease is known wherever peach growing is practiced. In the United States the general regions in which the more serious and constant injuries have been felt are apparently two, viz., the region of the Great Lakes and the Pacific Slope region, the latter including also districts in central and northern California.

Climatic relations. Plant pathologists are almost unanimous in the assertion that this fungous disease is most prevalent and most disastrous when the spring is cold and damp. Practical orchardists likewise concur in this opinion. Pierce about ten years ago collected statistics from about one hundred orchardists bearing upon

this point. Ninety-two per cent believed that a cold spring is favorable to the disease; more than seventy-five believed the wet weather also to be a factor. Six and seventeen per cent, respectively, expressed opinions opposing the view that cold and moisture are influencing factors. The memorable leaf-curl years in New York and Ohio, 1893, 1897, and 1898, were preceded by

Fig. 64. Peach Leaf Curl

cold and humid conditions during April, the time when the buds normally start. On the other hand, there is no record that the peach leaf curl has ever been particularly destructive during a warm and relatively dry spring. So firm is the opinion of a few of the practical growers as to this climatic relationship that they refuse to believe anything more than that the weather is the direct cause of the leaf curl. Moreover, heavy dews appear to be of insignificant environmental importance, and in view of the conditions developing dew, this would be anticipated.

Losses. The losses from leaf curl may not be so readily estimated as with many other fungous diseases, for the injury to the fruit is usually indirect, through the loss of leaves and the generally impaired vitality of the tree. Before the adoption of any rational preventive measures the losses in the United States were estimated at about three million dollars. In general, heavy losses in the South, on the Atlantic seaboard, and in the Southwest are infrequent, yet occasionally the damage is severe; while in the two regions previously mentioned as more severely visited, the losses are more nearly annual, and the entire crop may occasionally be destroyed.

Symptoms. The idea generally prevails that the leaf curl occurs only upon leaves and young branches, but the flowers and young fruit are likewise subject to attack. Since in the latter case the deformations are less conspicuous, and dropping of the parts affected is more prompt, it has often escaped attention. Leaves of the peach affected by this fungus may be detected as soon as the leaf buds have become slightly upfolded. The coloring of the young leaves is somewhat heightened, and as they unfold a curling and arching of the blades becomes prominent. The distortion may be confined to a small area on one leaf as one extreme, or it may occur on all leaves and petioles, as well as on the young stem which bears these (Fig. 64). As the leaves mature the green or reddish color is lost and the hypertrophied areas become pale or slightly discolored. Diseased shoots may attain more than twice their normal diameter and become pale in color. Further changes in the external appearance have been noted in a gray or mealy appearance of the surface, which occurs as a result of the production of the fungus superficially. Later the affected leaves turn brown and are finally defoliated. When defoliation is extensive the fruit crop will either be lost entirely or so stunted as to be of little value. Under favorable conditions a new crop of leaves will be promptly developed, but there is little or no evidence that this second crop of leaves may be affected even to a very limited extent. Gummy exudations sometimes appear on the enlarged twigs, particularly when the enlargement is not terminal. In case the terminal bud is not affected it may continue to grow later in the season, thus leaving the injured or swollen portion at the base of

the new growth. It was formerly supposed that this fungus was very largely propagated by a perennating mycelium, or by infections resulting during the summer and persisting in the woody parts until the following season, but as will be shown later, infections must generally occur as the buds unfold. The percentage resulting from a mycelium remaining alive in the hypertrophied twigs is very small. The badly affected twig dies and the mycelium with it. From other affected twigs diseased leaf buds are seldom produced (Fig. 65).

Fig. 65. One Healthy and Three Diseased Twigs of Peach; the Center Twigs recovered from the Attack

Susceptibility of host varieties. There is a great difference in the susceptibility of different varieties under similar conditions. Moreover, a single variety may show a difference in resistance when grown under diverse environmental conditions. A list of the most susceptible varieties in New York would not correspond with a list for California. Among susceptible varieties in the far West have been included such as the following: Crawford's Early and Late, Elberta and Salway, Heath King and Hale's Early, Lovell, Old Mixon Free, etc.; while for Ohio, Mountain Rose, Old Mixon, Globe, Elberta, and others are among those most affected.

A striking correlation seems to obtain between the serration of leaves and susceptibility to curl, the serrate varieties being very slightly susceptible as compared with those which have the glands of the leaves reniform or globose. Other interesting relationships have been suggested.

The fungus. While the leaf curl has evidently been known in England as a peach disease since 1821 or earlier, the fungus was first described by Berkeley in 1857. It has therefore been known to botanists for half a century. Infection takes place at the time of the opening of the buds (most frequently), but it may also result (occasionally) by the growth of a perennial mycelium from the old wood, in which it has rested over winter, into the expanding peach buds. According to Sadebeck, the mycelium winters over in the primary cortex and medullary tissues of the one-year-old branches.

In order to examine the mycelium to the best advantage a section should be made of a leaf or twig before the fungus has appeared upon the surface. The distribution of the mycelium within the host tissues may then be more easily followed, owing to the greater protoplasmic content. A microscopical study of hand or microtome sections indicates that the intercellular mycelium is quite generally distributed in the parenchyma of the leaf and in the cortex of the young stems. Three types of mycelium have been recognized (Pierce), and these may be detected in leaf or in shoot:

1. The most common type is designated *vegetative hyphæ*. These are very diverse, both in the diameter of the tubes and in the character of the branching, as shown in Fig. 66, *b*. Adjacent cells are separated by peculiar plate septa.

2. The second class of hyphæ are known as *distributive hyphæ*, and these are in the main composed of long cells of more or less uniform diameter, coursing, for the most part, parallel to the stem axis, and they are found abundantly in the pith or beneath the epidermal cells (Fig. 66, *c*).

3. *Fruiting hyphæ*. The vegetative hyphæ which have developed beneath the epidermis push up between the epidermal cells, and there is formed between the upper edges of the epidermal cells, and also between the epidermis and the cuticle, an extensive

development of short, modified hyphal cells (Fig. 66, *d*). These are properly the ascogenous cells, which by an abundant budding process form frequently an almost continuous layer beneath the cuticle. The asci develop from these ascogenous cells, as upward prolongations, pushing through the cuticle, while the original ascogenous cell is finally cut off by a cross wall as a stalk or foot

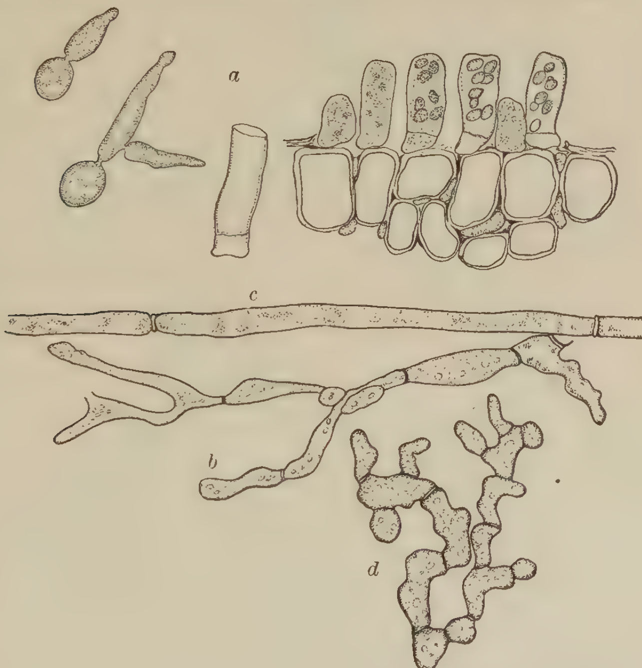


FIG. 66. EXOASCUS ON PEACH: ASCI, GERMINATING SPORES, AND HYPHÆ (*b*, *c*, and *d* after Pierce)

portion. The ascus is usually somewhat truncated at the apex and densely filled with protoplasm. It may measure 25–40 × 8–11 μ (ave. 30–35 × 9–10). As a rule it contains at maturity eight spores, although the number may vary from four to eight (Fig. 66, *a*). These asci often arise in such numbers that they form practically a continuous palisade-like layer over the fruiting surface.

The ascospores may bud before being thrown out of the ascus, but as a rule the spores are forcibly ejected from the ascus at maturity. Budding results in the successive production of conidia,

which may therefore be termed primary, secondary, etc. These conidia may be propagated for some time in beerwort. On the host germination may proceed normally, that is, by the direct production of a true germ tube; moreover, germination rather than budding is occasionally observed in culture. The grayish cast given to the surface of the leaf is due to the numerous asci, and a mealiness may become evident later from the abundance of conidia.

Infection. Since, as shown later, the disease may be in very large part prevented by spraying prior to the opening of the buds, it is evident that infection would seem to result, in general, by spores or conidia which have been caught in the bud scales, or, at any rate, which were adherent to the buds at the time of opening. It is therefore believed that the marked effect of conditions upon the prevalence of the leaf curl is brought about in this way: During cold, moist weather the young leaves within the bursting buds would be in a state described as suffused with water, and consequently attended by lowered vitality. The fungus would therefore gain entrance more readily. If, however, at this time the bud scales were well covered with a toxic fungicide, the germ tubes of the fungus would in most cases fail to cause infection. Again, the effect of conditions does not end with infection, and it is well known that the extent of the disease upon single leaves or shoots is greater when the cold, moist weather is persistent. It is, therefore, probable that the spread of the fungus throughout an infected leaf or shoot is directly assisted by the continuance of lessened vitality and water suffusion as growth progresses.

Control. Preventive measures for the leaf curl have been made a subject of careful investigation throughout many years. It has finally been clearly shown that a thorough application of a fungicide, preferably Bordeaux mixture, during the late winter or early spring just prior to the opening of the buds, may prevent from 90 to 95 per cent or more of the infections. I do not believe that subsequent sprayings are of any importance except in a case where the early spraying has been omitted; and the fungus being abundant, it is desired to cover up all parts of the plant with a spray so that the spores may be in large part killed as they are produced, or as budding is attempted.

III. PLUM POCKETS

Exoascus Pruni Fuckel

This fungus is the cause of the well-known deformities of the domestic plum, *Prunus domestica,* and it is very generally

FIG. 67. PLUM POCKETS ON CULTIVATED PRUNUS. (Photograph by H. H. Whetzel)

distributed throughout Europe and portions of the United States. The etiology and general life history is not sufficiently different from the peach leaf curl to require detailed treatment, but the

general characteristics of the abnormalities and special peculiarities of the fungus may be mentioned. The mycelium attacks the fruit buds and causes remarkable hypertrophies in the developing ovaries. The mesocarpic tissue is invaded, whereby it is stimulated to the production of an abundant spongy growth and the whole form of the plum is enlarged and distorted. Apparently the connection of the stone with its usual source of nutrition is broken up and no stone is developed, or else only a rudimentary structure. It is claimed that the mycelium is perennial, that here infection results by the growth of this mycelium into the young shoots and

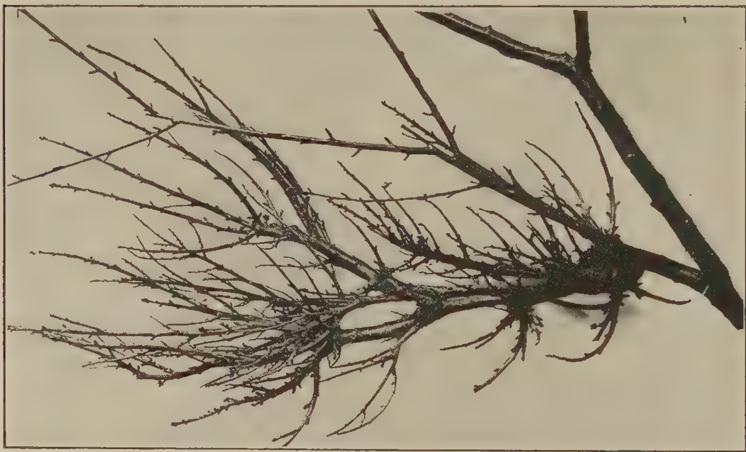


FIG. 68. WITCHES' BROOM ON CHERRY, PRODUCED BY EXOASCUS
(Photograph by F. C. Stewart)

ovaries in the spring. This point requires further investigation. As in the case of the peach leaf curl fungus, the ascogenous cells are developed beneath the cuticle and the elongating asci rupture the latter. The asci are densely crowded together and do not all mature at the same time. In general, the asci are $30–60 \times 7–12\,\mu$. Robinson notes a certain dimorphism in the asci, slender ones measuring $43–60 \times 5.5–7$, and stout forms $27–35 \times 9–12\,\mu$. In several instances I have attempted to inoculate young plums with spore-bearing material received from farther south, but such experiments have invariably failed. In general, a study of infection phenomena in the Exoascaceæ would seem to be of much interest.

IV. WITCHES' BROOM OF THE CHERRY

Exoascus Cerasi Fuckel

This fungus is very common on both *Prunus avium* and *Prunus Cerasus* in Europe. It has been reported infrequent in this country. The mycelium attacks the branches, and the stimulation due to its presence results in the formation of numerous twigs somewhat in the form of a loose broom (Fig. 68). According to some observers the twigs may be slightly thickened, although others claim that there is no abnormality in the latter. The leaves on affected twigs are also penetrated by the mycelium and they become somewhat reddish and wrinkled or crumpled. The asci develop upon the leaves, and measure, according to Sadebeck, 35–50 × 7–10 μ (25–33 × 6–9 in specimens studied by Atkinson). During the flowering period of *Prunus Cerasus* the witches' brooms are very conspicuous, since the broom usually bears leaves only.

Prevention in this case requires the destruction of all affected branches, as well, probably, as a thorough spraying about the time the asci are mature, and a subsequent one when the buds swell the following spring.

Of the many other species of Exoascus the majority are parasitic upon different species of Prunus, while Alnus, Populus, Acer, Æsculus, Carpinus, Cratægus, Pyrus, Quercus, Ulmus, and other plants are also hosts.

V. HELOTIACEÆ

The Helotiaceæ are Discomycetes of which the fruiting body is a distinct apothecium or cup. In texture these fungi may vary from wax-like to a rather tough consistency. The body is at first almost spherical and nearly or quite closed. With growth and differentiation it opens into the characteristic cup, sessile or supported by a stalk varying in length in different species. The sterile tissue of the cup is pseudoparenchymatous. The cylindrical asci arise from a hyphal-like hymenium, and each ascus contains eight spores. At maturity the ascus opens at the apex and forcibly ejects the spores, the latter being hyaline, diverse in form, and 1–8 celled. Filamentous paraphyses are present. Sclerotinia and Dasyscypha may be mentioned as containing parasitic species.

Of the twenty-five genera of this family, the genus Sclerotinia includes the most important parasitic species. It is characterized particularly by the fact that typically the fruit body arises from a sclerotium, which may be defined as a compact mass of hyphal elements, sometimes distinctly pseudoparenchymatous or sclerotial in texture, serving commonly as a resting or more resistant mycelial stage. The sclerotium may be developed upon the living host or it may form after the death of the diseased structure. The apothecium is usually borne in this case on a rather long stalk, and it is smooth and more or less brown in color. The cylindrical asci bear in uniseriate fashion eight usually elliptical spores. Conidial and chlamydosporic stages may be present.

VI. SCLEROTINIA

De Bary, A. Ueber einige Sclerotinien und Sclerotinienkrankheiten. Bot. Zeitg. **44**: 377–387 (et seq.). 1886.

Wakker, J. H. Ueber die Infection der Nährpflanzen durch parasitische Peziza-(Sclerotinia-) arten. Bot. Centrbl. **29**: 309–313, 342–346. 1887.

Woronin, M. Ueber die Sclerotienkrankheiten der Vaccinieen-Beeren. Mém. de l'Acad. imp. de Sci. de St. Pétersbourg **36** (sér. 8): 1888.

Many species of Sclerotinia produce diseases of plants, and although several species have been carefully studied, there is much in the way of unconfirmed data. A monographic study of the genus is greatly needed. The apothecial or perfect stage is not developed, as a rule, until the mycelium, or a sclerotium, has undergone a period of rest. In several cases it is well established that the conidial stages are members of the form genus Monilia. It is also declared that other species include Botrytis forms in their life cycles. For convenience the following tentative classification of species of Sclerotinia is suggested:

1. Species comprising in their life cycle not only apothecia, but also a Monilia stage, that is, with conidia produced in chains, the latter frequently separated one from another by special structural devices.

a. Species in which both spore forms may be produced upon the same host; such as *Sclerotinia fructigena*, *S. Vaccinii*, *S. Aucupariæ*, *S. baccarum*, *S. megalospora*, and *S. Oxycocci*.

b. Species whose life cycles are not complete upon a single host; *Sclerotinia heteroica* and *S. Rhododendri*.

2. Species which may embrace a form of Botrytis as a conidial stage; *Sclerotinia Fuckeliana*.

3. Species in which no conidial stages have been convincingly demonstrated; *Sclerotinia Libertiana*, *S. Betulæ*, and *S. Trifoliorum*.

VII. BROWN ROT OF STONE FRUITS

Sclerotinia fructigena (Pers.) Schroet.[1]

ADERHOLD, RUD. Ueber eine vermuthliche zu Monilia fructigena Pers. gehörige Sclerotinia. Ber. d. deut. bot. Ges. **22**: 262–266. 1904.

HUMPHREY, J. E. On Monilia fructigena. Bot. Gaz. **18**: 85–93. *pl. 7.* 1893.

NORTON, J. B. S. Sclerotinia fructigena. Trans. Acad. Sci. of St. Louis **12**: 91–97. *pls. 18–21.* 1902.

QUAINTANCE, A. L. The Brown Rot of Peaches, Plums, and Other Fruits. Ga. Agl. Exp. Sta. Bullt. **50**: 237–269. *figs. 1–9.* 1900.

SMITH, ERW. F. Peach Blight, *Monilia fructigena*, Pers. Journ. Myc. **5**: 123–134. *pls. 5, 6.*

SORAUER, P. Erkrankungsfalle durch Monilia. Zeitsch. f. Pflanzenkr. **9**: 225–235. *pl. 4.* 1899.

WEHMER, C. Monilia fructigena Pers. (= Sclerotinia fructigena m.) und die Monilia Krankheit der Obstbäume. Ber. der Deut. Bot. Ges. **16**: 298–307. *pl. 18.* 1898.

WORONIN, M. Ueber Sclerotinia cinerea und Sclerotinia fructigena. Mém. de l'Acad. imp. d. Sci. de St. Pétersbourg. VIII^{e}–Sér. Phys.-Math. Cl. **10** (5): 1–38. *pls. 1–6.* 1899.

The fungus causing the brown rot of fruits has been known botanically for half a century, but its great economic importance has only been appreciated during the past twenty years. It is now a well-known disease wherever the peach is grown throughout Europe and America. The conditions under which great injury results are, however, not general in all the countries named; and therefore it may be very destructive one year and of relatively slight importance the following season. Whether warm or cool, moist weather is favorable to the spread of the disease, but the muggy weather of midsummer is particularly disastrous to the stone-fruit crop, on account of the rapid spread of the disease under such conditions.

[1] Under this title is discussed the widespread rot of stone fruits. Two species of Sclerotinia may, according to the work of Woronin, be distinguished as causing somewhat different types of disease; these species are *Sclerotinia fructigena* and *Sclerotinia cinerea*. It is claimed that there are no observable differences in the mycelium of the two species, but that differences are evident in the color of the spore masses and in the susceptibility of hosts to the two forms. In *Sclerotinia fructigena* the spores are described as light brownish-yellow, or ochraceous, while in the other they are invariably gray. Moreover, in the former the spores are larger, averaging $20.9 \times 12.1\,\mu$, while the latter average $12.1 \times 8.8\,\mu$. *Sclerotinia cinerea* is said to be most abundant on the common stone fruits, whereas *Sclerotinia fructigena* is also found on pomaceous fruits. The above view does not appear to be that generally held by American pathologists, and it is not uniformly accepted in Europe. We shall, therefore, use the name *Sclerotinia fructigena* to designate this rot-disease of diverse stone fruits.

Extent of losses. The years when the greatest injury has been reported from various sections of this country are as follows: In 1887 Dr. Erwin F. Smith reported it from Maryland and Delaware. The extent of the injury probably resulted in a shortage of the total crop estimated at 800,000 baskets of peaches. It was also very abundant in 1891 and 1893. Again, during subsequent years, it has been of considerable importance in the Delaware and Chesapeake peninsula. In 1897 an almost total loss of the crop in Alabama was reported, the following year being somewhat less disastrous. Quaintance states that the year 1900 was the worst in the history of commercial peach and plum growing in Georgia. He estimated the loss at 40 per cent of the total crop. This would mean a loss of between $500,000 and $700,000 for that state alone.

Symptoms. The name *brown rot* has long been applied to this disease, and it is the one in most common use, although many others, particularly ripe rot, are also employed in some sections. This disease affects practically all stone fruits (Prunus spp.), very few varieties of either peach, apricot, nectarine, plum, or cherry being free from it during seasons favorable to the fungus. The fruits are the most common seat of injury, but other vegetative parts are likewise susceptible. As a rule the fruits are apparently most easily attacked after they have become half grown, and the susceptibility increases from this time to ripening. Fruits in clusters, under which conditions moisture would be held, are more readily injured.

The disease first makes itself evident as a small, dark brown, decayed spot. This spot increases in extent until the whole fruit is infested, but there is at first no diminution in size, and no sunken area develops. Before the whole fruit has become decayed, however, evidences of a superficial development of the conidia of the fungus may appear. As a rule, however, the fungus develops its spores only after the fruit has decayed considerably. The fungus then breaks through the surface in the form of small tufts, consisting of masses of conidiophores with an abundant production of conidia, the appearance being as shown in Fig. 69.

The flowers may also succumb, and that is more commonly the case the year after an unusual outbreak of the disease, due

FIG. 69. BROWN ROT OF PLUM: MONILIA STAGE

generally to the fact that the old mummied fruits remaining on the twigs in large numbers serve to cause a very general infection at the time of blossoming. The twigs are also susceptible, but it has been quite definitely shown that infection of the twigs results only

when either flowers or fruit produced on the twigs have already fallen prey to the disease. In other words, the fungus must grow directly from the fruit or blossom into the young twigs, since it cannot readily penetrate the epidermis of the latter. Inoculation of the fungus into cuts on the bark will, however, also result in a twig infection. The effect of the fungus upon the twig is to produce a blight, the twig being completely killed as the disease progresses (Fig. 70). Peaches and apricots are more subject to the twig blight than other stone fruits.

Fig. 70. Apricot Twig killed by the Brown Rot Fungus

Mummied fruits. The fruit which has decayed may fall to the ground or hang upon the trees, gradually shrinking with evaporation each to a crumpled, dried mass, generally known as a mummy. These mummied fruits are the chief source of infection the following season under ordinary conditions. It has been determined that the spores produced one summer may, under certain conditions at least, live over until the following spring. Further, the mycelium within the mummied fruits more readily lives until conditions favorable for growth the following season. It is also possible that the spores which have been blown about and adhere to bud scales, etc., may likewise cause infection the following year.

Rot in market fruit. Not only is this fungus a cause of considerable loss in the orchard, but it also affects the fruit in shipment or on the market. When the spores are abundant in the orchard,

every fruit having perhaps some on its surface, these spores may germinate, under favorable conditions in transit, and cause infection of the fruit in bulk, so that a shipment which showed great promise as it left the orchard may reach the market in practically worthless condition.

Susceptibility of hosts. No very extensive data have been accumulated with reference to the resistance or susceptibility of the many varieties of stone fruits in different sections of the country. In general, however, it would appear that among peaches the sorts densely covered with hairs or down, such as the Alexander, Hill's Chili, and Triumph, are unusually susceptible. Among the more resistant sorts are to be found the Carman, Early Crawford, Elberta, Chinese Cling, and some others. Among the plums the Japanese varieties suffer generally in most sections of the country. The American group of plums is also susceptible, and apparently more susceptible at the South than farther north. The Wild Goose and Marietta plums are much less affected in all regions. The native cherries are more resistant than such as the Montmorency.

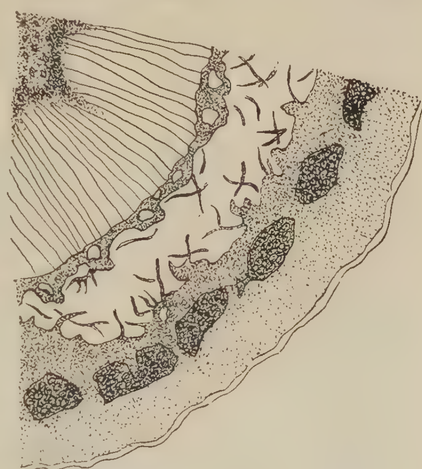


FIG. 71. SECTION OF PEACH TWIG AFFECTED WITH THE MONILIA. (After Erw. F. Smith)

The fungus. The small tufts of the fungus, commonly called mold tufts, which appear on affected fruits and occasionally on blighted twigs are made up of conidiophores and the numerous conidia to which they give rise. The production of the aërial conidia usually indicates that the substratum is considerably penetrated by the mycelium. This mycelium is light brown in color, rather closely septate, considerably branched, unequal in diameter, and somewhat nodulose or occasionally cellular in appearance. It is often vacuolate and may contain bodies differentiated as resting mycelial cells, or perhaps properly designated chlamydospores.

On blighted branches of the peach the mycelium has been found (Smith) to grow most abundantly in the cambium and soft bast, these tissues disappearing in large measure with the formation of extensive gum pockets (Fig. 71).

The conidiophores arise as short hyphæ, which soon become septate at the extremities, branched and nodulose. The branching proceeds in an indefinite and usually irregular or semidichotomous fashion (Fig. 72, *a* and *b*). From the apex of these branches toward the base conidia are rapidly cut off, these cells remaining for a time simply moniliform or as branched chains, each constriction between the nodulations eventually marking the line of

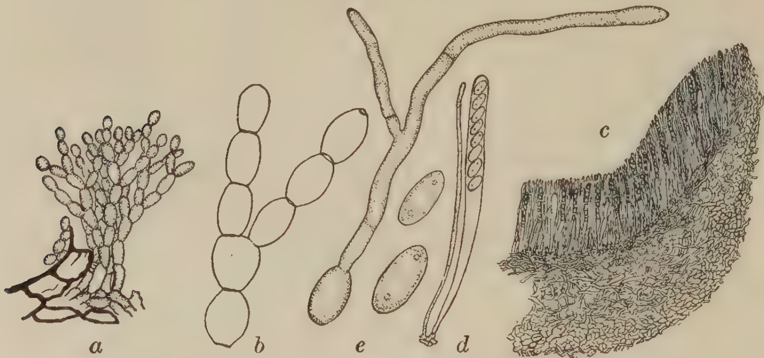


FIG. 72. *SCLEROTINIA FRUCTIGENA:* CONIDIOPHORES AND CONIDIA, SECTION OF APOTHECIUM, ASCUS, AND ASCOSPORES

separation between adjacent spores. The spores germinate readily, and often while still massed in the tuft of conidiophores, that is, before being blown or brushed away. Germination studies have shown that many of the conidia may live through until the succeeding season, and, as indicated, the mycelium is even more capable of effective hibernation.

Ordinarily no apothecial stage has been observed to intervene regularly in the life cycle of this fungus, and the ascosporous or Sclerotinia stage is not believed to be important to continue the propagation of the fungus. During the spring of 1902 the Sclerotinia stage was found (Norton) quite commonly in the orchards of Maryland. The apothecia were discovered arising from sclerotia, which might be developed either within the tissues or on

the surface of the mummied fruits. The fruits upon which this stage appeared had been lightly covered with sandy soil for at least a year. In 1906 this stage was extremely common throughout the West. Conditions seemed to be most favorable for its development where the fruit had lain for eighteen months in little depressions in the sod, and fairly well covered by grass débris. The stalk or stipe of the apothecium was from .5 to 3 cm. in length, depending upon the distance of the mummy beneath the soil. The stipe is dark brown and the slightly bell-shaped disk is a shade lighter. The latter is usually 5–8 mm. in diameter, though it may range from 2 to 15 mm. The general appearance

Fig. 73. Apothecia of Sclerotinia from Mummied Plums

of the apothecia is shown in Fig. 73. The stipe consists of a medulla of elongated, intertwined, brown cells and a cortex of shorter, darker ones, the latter being continued in a tissue projecting beyond the hymenium. The asci are cylindrical-clavate, $125–215 \times 7–10\,\mu$.[1] They arise from a dense layer of small hyphæ, differing from the general medullary hyphæ merely in being more closely intertwined (Fig. 72, *c* and *d*). The ascospores are ellipsoidal and measure $10–15 \times 5–8\,\mu$. They are obliquely uniseriate, or subseriate. The paraphyses are characteristic of many Pezizaceæ, — hyaline, septate, simple or branched, filiform, and slightly swollen at the tips.

[1] Reade, J. M. Preliminary Notes on Some Species of Sclerotinia. Annales Mycologici **6**: 109–116. 1908.

Control. Preventive treatment should be begun in late winter or very early spring and must consider two possible sources of infection: (1) conidia adherent to bark or bud scales, and (2) the mummied, diseased fruits or blighted twigs. A thorough spraying, equivalent to disinfection with strong Bordeaux (6–6–50), would be effectual against the free conidia. In addition to such spraying, however (and it may be well to do this in late autumn), it is essential to destroy the old, diseased fruits. Prune them or knock them from their attachment to the twigs, rake them from beneath the trees, and destroy or turn under deeply. Spores may be blown long distances, however, so that an appearance of the disease may be expected at any time during the growing season, aside from the fact that it is hardly possible to kill all adherent conidia. In some sections of the country a 3–4–50 Bordeaux made with good lime has been used advantageously after foliage and fruit are well developed, with no injury resulting either to peaches or Japanese plums; but this is not uniformly the case, and seasonal conditions unquestionably have a considerable influence on the amount of injury caused by the spray. It might, where practicable, be employed until the fruits are more than half grown, after which time some other liquid spray or Bordeaux dust should be substituted. It is sometimes advisable to use a copper acetate solution (6 ounces to 50 gallons) when color begins to appear in the fruit. During a season of infrequent rains the writer has used a lime spray with some success.

Some experiments have recently been made[1] with the lime-sulfur spray, and it is sufficiently promising to warrant trial. Apparently, the safest and most effective preparation is made by mixing 10 pounds of sulfur and 15 pounds of good lime. Upon slaking the lime the sulfur is "self-cooked" from the heat generated, and the mixture is finally diluted to 50 gallons. During a single fairly dry season (a most favorable one for this mixture) the loss has been considerably reduced, — 73 per cent in the unsprayed plot as compared with from 10 to 30 per cent in the sprayed.

[1] Faurot, F. W. Brown Rot of Peach. Mo. State Hort. Soc. Rept. (1907): 285–289. (Scott, who coöperated in this work, has also published the results of these experiments in detail. Compare Bureau Plant Ind., U. S. Dept. Agl, Circular **1**: 12–16. 1908.)

Sclerotinia Vaccinii (Wor.) Rehm.[1] This species occurs on shoots, leaves, and berries of the cowberry, *Vaccinium Vitis-idæa*. In this fungus the chains of conidia show characteristic "disjunctors." The latter are fusiform cellulose structures separating the spores, and apparently important in dissemination. The conidial surface possesses an amygdaline aroma, by which insects are supposedly attracted. The diseased berries are yellow-brown when ripe. From sclerotia in mummied fruits which have lain on the ground over winter the apothecia are developed. The mature ascospores measure 14–17 × 7–9 μ.

Sclerotinia Aucupariæ Ledw.[2] has been found in Finland and in Germany on the leaves and fruit of *Pirus Aucuparia*.

Sclerotinia baccarum Schroet.[3] is the cause of the sclerotial disease of the bilberry, *Vaccinium Myrtillus*. In this species the apothecia are relatively large and stout, measuring 5–10 mm. in diameter, with stalks often 5 cm. in length. The spores are 18–20 × 9 μ.

Sclerotinia megalospora Wor.,[3] on the berries and leaves of the crowberry, *Empetrum nigrum*, has large, more nearly spherical conidia than those above described, and the ascospores, invested with a distinct gelatinous envelope, measure 20–25 × 14–16 μ.

Sclerotinia Oxycocci Wor.[3] produces the sclerotial disease of the cranberry, *Vaccinium Oxycoccus*. This species is morphologically and physiologically interesting on account of the difference in size of the spores, four being large and capable of germination, while the other four are considered to be ill developed and incapable of germination. This suggests an interesting differentiation of the nuclei. Even the larger spores are relatively small for this group, measuring 12–14 × 6–7 μ.

Sclerotinia heteroica Wor. & Nawasch.[4] According to Woronin this species produces upon *Vaccinium uliginosum* a conidial stage, which conidia are able successfully to infest the ovaries of *Ledum palustre*, but no conidia are produced on Ledum. On the latter host, however, the sclerotial stage is developed. This fungus

[1] Woronin. Ueber die Sclerotienkrankheiten d. Vaccinieen-Beeren, *l. c.*
[2] Woronin. Ber. d. deut. bot. Ges. **9**: 102–103.
[3] Woronin. Ueber die Sclerotienkrankheiten d. Vaccinieen-Beeren, *l. c.*
[4] Nawaschin. Ber. d. deut. bot. Ges. **12**: 117–119.

apparently requires two hosts to complete its development and is, therefore, an instance of what is denoted heterœcism, a condition discussed more at length under the rust fungi.

Sclerotinia Rhododendri Fischer,[1] like the preceding, appears to be heterœcious in character. It is found on *Rhododendron ferrugineum* and *Rhododendron hirsutum*.

VIII. GRAY MOLD, OR BOTRYTIS DISEASE

Sclerotinia Fuckeliana De Bary

Brooks, F. T. Observations on the Biology of Botrytis cinerea. Ann. Bot. **22**: 479–484. *figs. 1–4.* 1908.

Istvánffi, G. de. Études microbiologiques et mycologiques sur le rot gris de la vigne. Ann. d. l'institut central ampél. roy. Hongrois (1905): 183–360.

Kissling, E. Zur Biologie der Botrytis cinerea. Hedwigia **28**: 227–256. 1889.

Nordhausen, M. Beiträge zur Biologie parasitären Pilze. Jahrb. f. wiss. Bot. **33**: 1–46. 1898.

Smith, R. E. Botrytis and Sclerotinia. Botan. Gaz. **29**: 369–407. *pls. 25–27. figs. 1–3.* 1900.

Smith, R. E. The Parasitism of Botrytis cinerea. Botan. Gaz. **38**: 421–436. 1902.

Occurrence and effects. In the conidial stage this is one of the most common fungi known upon vegetation. It may propagate itself indefinitely as a saprophyte upon fallen or dejected flowers and leaves, or upon decaying organic matter. Again, it may, as a parasite, produce a variety of rots, decays, or stem diseases, especially in greenhouse or other plants grown under moist, warm conditions.

In Europe it is important as a disease of the leaves and fruit of the grape. While such injuries may be serious, the abundance of this fungus on the fruit, in certain regions, late in the season gives promise of high-class wine production. The grapes are then juicy and rich in sugar. It attacks other woody plants. Smith regards the *Botrytis Douglasii* Tubeuf,[2] reported destructive to young conifers, as synonymous with this species, and he has found it responsible for a disease of the linden (*Tilia parviflora*) in the nursery. It seems to be the less frequent cause of lettuce "drop" in the greenhouse. This disease, subsequently discussed

[1] Fischer. Ber. d. schweiz. bot. Ges. 1894.

[2] Tubeuf, K. von. Botan. Centrbl. **33**: 347. 1888.

more at length, may begin and develop in various ways when Botrytis is the cause, but it is finally known by the complete collapse of the lettuce heads due to the death of the stem and leaf bases. The conidial stage is also associated with various damping-off diseases, and it is believed by Smith to be the organism studied by Marshall Ward as the cause of an important lily disease.[1] In all cases the conidial stage of the fungus may develop abundantly upon the dead parts, and it has the appearance of a gray mold.

FIG. 74. *Botrytis cinerea.* (After R. E. Smith)
a, portion of conidiophore; *b*, organ of attachment

The fungus: morphology and biology. Under *Sclerotinia Fuckeliana* it is intended to include the forms of disease which may be attributed in Europe to *Botrytis cinerea* Pers. and in America to *Botrytis vulgaris* Fr. It has been satisfactorily demonstrated that these two names apply to a single species, a typical conidiophore of which is illustrated in Fig. 74. The observations of De Bary first connected this conidial stage with an apothecial form, *Sclerotinia Fuckeliana*, produced from sclerotia of the Botrytis on grape. Subsequently doubt arose regarding this connection, since many observers failed repeatedly to secure under any

[1] Ward, H. Marshall. Ann. Bot. **2**: 319–382. *pls. 20–24.* 1888.

conditions the perfect form from sclerotia of the Botrytis. It would seem that Istvánffi has now secured substantial proof that these are pleomorphic stages of a single fungus.

Much interesting biological work has been done upon this fungus. Infection results most readily from sclerotia or from a mycelium which has been growing saprophytically. Infection frequently fails when conidia germinate directly upon the surfaces of delicate parts. Upon penetrating a plant there is, first, a direct poisoning effect, supposedly due to oxalic acid, resulting in the death of adjacent cells; and, second, there is more or less digestion of the cell contents and membranes.

FIG. 75. *Sclerotinia Libertiana.* (After R. E. Smith)
a, sclerotia and apothecium; *b*, penetration of hyphæ

Control. In the case of this fungus, as well as the species of Sclerotinia next discussed, good sanitation is important. Nevertheless, in the greenhouse it may be necessary to sterilize the soil in order to control the disease effectively when it becomes virulent.

IX. LETTUCE DROP

Sclerotinia Libertiana Fuckel

HUMPHREY, J. E. Diseases of the Cucumber Plant. A Sclerotium Disease. Mass. Agl. Exp. Sta. Rept. **10**: 212–224. *pls. 1–2.* 1892.

SMITH, R. E. Botrytis and Sclerotinia: Their Relation to Certain Plant Diseases and to Each Other. Bot. Gaz. **29**: 369–407. *pls. 25–27.*

STONE, G. E., and SMITH, R. E. "Drop" of Lettuce. Mass. (Hatch) Exp. Sta. Rept. **9**: 79–81. 1897. (Compare, also, **10**: 55–58, 1898; and **11**: 149–151, 1899.)

Symptoms, effects, and hosts. It is difficult to determine how many of the reported sclerotial diseases of greenhouse and garden crops may be due to this fungus. It is unquestionably, however, one of the most disastrous of the sclerotium-producing fungi, and it is, moreover, widely distributed and not readily controlled. So far as can be judged from the studies and experiments which have been made, it is the cause of the worst type of the lettuce "drop," a disease of great importance in the greenhouses of the eastern states.

As this disease commonly occurs there is little or no evidence of the incipient stages in the form of definite spots or ulcers. The host plants may show some evidences of flagging, in a short time there are indications of water-soaked areas over the stem and basal portions of leaves, and finally the whole plant collapses and melts into a formless mass.

Even from early evidences of the disease fungus threads may appear upon the surface of the leaf, and this mycelium may become superficially conspicuous, even resulting in the development of small sclerotia. These appear first as white specks and later take the form of deep black, rather irregular sclerotia, as shown in Fig. 75, *a*. This fungus quickly spreads from plant to plant through the soil, and furthermore, in its relation to healthy plants, results almost invariably in the production of the disease. De Bary showed that ascospores are commonly ineffective in producing direct infection, but sclerotia or bits of the mycelium may serve for inoculation purposes. The *Sclerotinia Libertiana* type of sclerotium will yield almost invariably the apothecia of the Sclerotinia.

This fungus is apparently widespread. It has been reported by various observers as a cause of destructive diseases of hemp, rape, cucumbers, and of many forced vegetables and bulbous plants. A disease of the tobacco, discussed by Clinton,[1] has also been attributed to this fungus.

The life cycle. In no case has it been possible positively to identify a conidial stage in the life cycle of this species, although *Botrytis cinerea* has frequently been found upon plants unquestionably

[1] Clinton, G. P. Tobacco Diseases. Stem Rot. Conn. Agl. Exp. Sta. Rept. (1906): 326–329. *pls. 20 a, b; 21 a.*

affected with this sclerotial disease. From a series of experiments extending through several years, Smith was unable by any means to produce a conidial stage from cultures of the *Sclerotinia Libertiana* sclerotia, and he believes, moreover, that there exists another type of this fungus in which no conidia are produced and in which the more minute sclerotia are incapable of producing the apothecia. Whether or not there is any connection between the large sclerotinial type, which must be designated as *Sclerotinia Libertiana*, and the smaller type above referred to, it is unquestionably true that there exists a disease of lettuce and other greenhouse plants of which the small sclerotium-producing

FIG. 76. THE LETTUCE DROP: CONTROL (HEALTHY) AND INOCULATED (DISEASED) PLANTS

fungus is the cause. The writer has found this type of the fungus to be the cause of an important disease of lettuce in New York and Boston, and inoculation experiments have invariably shown the disease to be unusually virulent (Fig. 76). *Sclerotinia Libertiana* has been several times reported as an important disease of the cucumber, and according to Humphrey it is rather common in the cucumber houses in Massachusetts. Humphrey supposed, however, that the Botrytis which he found upon diseased plants was connected with the sclerotial stage, but no sufficient proof of such connection is afforded by the work which he reports.

The sclerotia of this species are said to reach 3 cm. in length in exceptional cases. The asci are cylindrical, and measure 130–135 × 8–10 μ, while the spores are small, — 9–13 × 4–6.5 μ.

X. STEM ROT OF CLOVER

Sclerotinia Trifoliorum Eriks.

CHESTER, F. D. Rot of the Scarlet Clover. Del. Agl. Exp. Sta. Rept. **3**: 84–88. 1890.
ERIKSSON, J. Bot. Centrbl. **1**: 296.

This fungus is occasionally very destructive to various species of clover (Trifolium) in Europe, and it has several times been reported as epidemic in the United States. In this country, however, it is not so widely distributed or so constant in its injurious effects as to have been often observed. The effect of this fungus upon the host is to produce a decay near the base of the stool, or practically at the surface of the ground, as the result of which the plant wilts. The mycelium, which is from the beginning evident on the surface, invades the tissues and ordinarily by the time that the plant is killed numerous small, black sclerotia are produced upon the surface of the affected parts. The sclerotia vary in size from 1 to 5 or 6 mm. in diameter. Sown upon moist sand or wintered upon the decaying remains of the host there are produced the following spring the brown apothecia characteristic of this species. The asci are long cylindrical, about $180 \times 12\,\mu$. Ascospores, which are disseminated in the early spring, lose their power of germination upon being dried, and it would seem, therefore, that they must penetrate the host at this time. It is claimed, on the other hand, that the sclerotia may retain their vitality for a period of several years if the conditions are unfavorable for germination. Some regard this fungus as identical with *Sclerotinia Libertiana*.

Sclerotinia Betulæ Wor.[1] This birch catkin disease is common in birch forests of Russia. Sclerotia, so far as is known, are produced during the development of the catkins, falling and remaining on the ground over winter. The apothecia are formed the following spring, each sclerotium producing several small apothecia of light color. The fungus has also been found in Europe, Asia, and America.

Sclerotinia tuberosa (Hedw.) Fckl. develops enormous sclerotia on the rhizomes of *Anemone nemorosa*.

[1] Tubeuf. Diseases of Plants, *l. c.*, 261.

XI. LARCH CANKER

Dasyscypha Willkommii Hartig.

HARTIG, R. Die Lärchenkrankheiten, insbesondere der Lärchenkrebspilz. Untersuch. aus d. Forstbotan. Institut München **1**: 63–87. 1880.

Occurrence and effects. The larch canker is one of the most important diseases of this host in certain districts of Europe. It is particularly abundant in the moist, marshy, mountain meadows, but is seldom of importance on hillsides or slopes. The fungus is a typical canker-producing organism, and, so far as is known, it gains entrance to the host only through wounds. It spreads most rapidly in the phloem elements and rapidly causes the death of the bark. The diseased areas become shrunken and brown. The bark may peel away in places and pronounced cankers develop. The fungus appears to spread rapidly only during seasons when the host plant is comparatively inactive, as during the autumn and winter. The wounds of the previous year may, therefore, be practically healed over during the growing season, but the following autumn the fungus continues its spread, and in time large limbs or trunks may be completely girdled and death result. The needles on affected twigs begin to show the presence of the fungus during the late summer.

The fungus. Upon the death of the bark the fungus appears superficially in the form of creamy or yellowish-white stromatic tufts. Upon the minute conidiophores there are produced simple hyaline conidia. The latter have not been germinated and do not appear to be important in the immediate distribution of the fungus. Later in the season the apothecia may appear on the diseased areas if there is sufficient moisture. The apothecia are short stalked, almost sessile, yellowish without, and orange colored within. The asci measure about $120 \times 9\,\mu$. They are cylindrical in form and contain invariably eight ovoidal, unicellular spores. Between the asci are interspersed a considerable number of filiform paraphyses. Inoculation experiments have demonstrated that this fungus is the cause of the canker with which it is associated. No preventive measures can be recommended when the fungus is once established on larch plantations, and, therefore, in locating new plantations, one should bear in mind the conditions under which the fungus is most disastrous.

XII. MOLLISIACEÆ

This family differs from the Helotiaceæ largely in texture, the former being tougher, and as a rule made up of hyphal cells modified in a prosenchymatic or fibrous manner. The spores are hyaline and very similar to those of the Helotiaceæ. The only genus of importance in producing plant diseases is Pseudopeziza.

FIG. 77 *a*. ALFALFA LEAF SPOT. (Photograph by H. H. Whetzel)

Pseudopeziza. In this genus the apothecium is formed beneath the epidermis, which is later ruptured, and the mature fruit body is relatively simple in structure and shallow. The asci contain eight unicellular spores.

XIII. ALFALFA LEAF SPOT

Pseudopeziza Medicaginis (Lib.) Sacc.

COMBS, ROBT. The Alfalfa Leaf Spot Disease. Iowa Agl. Exp. Sta. Bullt. **36**: 858–859.

The alfalfa leaf spot is often very abundant both in Europe and America, and particularly injurious during rather dry seasons.

Fig. 77 *b*. Alfalfa defoliated by the Leaf Spot Fungus. (Photograph by H. H. Whetzel)

Small sooty brown or black spots about $\frac{1}{16}$ inch in diameter are produced, first evident on the upper surfaces of the leaves (Fig. 78). In these spots there appear later in the season the relatively simple, sessile apothecia, which are formed beneath the epidermis and break through at maturity. The spots are often very numerous, causing defoliation of many of the leaves by the latter part of summer. These structures are saucer-shaped, flat, and light in color, at first fleshy in texture. The club-shaped asci bear eight unicellular colorless spores in two series, measuring 10–14 μ in length. Paraphyses are also present. The mycelium is very local and confined to the area of the spots. This fungus is very closely related to the species causing a leaf spot of clover, *Pseudopeziza Trifolii*, and with this species it may be identical. No practical method of controlling this disease has been developed.

XIV. ANTHRACNOSE OF CURRANTS

Pseudopeziza Ribis Kleb.

Dudley, W. R. Anthracnose of Currants. Cornell Agl. Exp. Sta. Bullt. **15**: 196–198. 1889.

Klebahn, H. Untersuchungen über einige Fungi imperfecti und die zugehörigen Ascomycetemforem. III Glœosporium Ribis (Lib.) Mont. and Desm. Zeitsch. f. Pflanzenkr. **16**: 65–83. *pls. 3–4.* 1906.

Stewart, F. C. An Epidemic of Currant Anthracnose. N. Y. (Geneva) Agl. Exp. Sta. Bullt. **199**: 64–80. 1901.

Distribution and occurrence. This anthracnose is a disease well known in Europe and America. Periodically since 1884 it has been mentioned as a destructive fungus to both white and red currants in New York. The fungus has also been found upon black currants and gooseberries, but it has never, apparently, amounted to an epidemic. Among red currants Stewart observed that Prince Albert and President Wilder were practically free from injury where Fay's Prolific and Victoria were seriously affected.

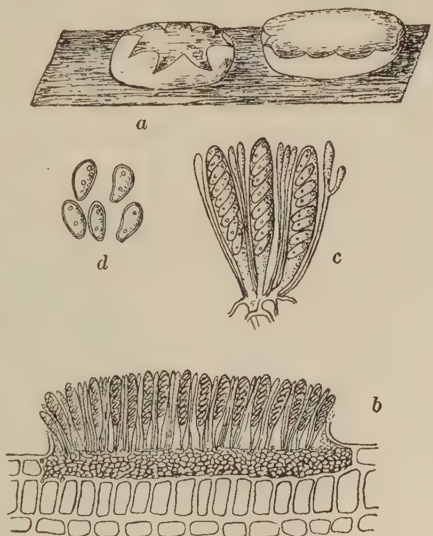


FIG. 78. *Pseudopeziza Medicaginis*: Structural Features. (After Comes)

Affected leaves are more or less covered with small brown spots, as shown in Fig. 158. When the trouble is serious the leaves turn yellow and drop. The fungus also occurs on petioles, young canes, fruit stalks, and fruits. It is believed that it may pass the winter on the canes.

The fungus. Until 1906 this fungus was known by an imperfect stage alone, which like that of the bitter rot of the apple subsequently discussed was referred to the genus Glœosporium, and bore the name *Glœosporium Ribis*. The Glœosporial stage (cf. Glœosporium) is in fact the only stage of the fungus which is produced upon the growing plant. The pustules or acervuli consist of a stromatic portion from which arise numerous conidiophores, bearing elliptical or strongly curved, falcate conidia. These fruiting masses rupture the epidermis and the spores escape in a gelatinous mass. The acervuli are produced very abundantly on both surfaces of the leaves but particularly upon the upper surfaces. The spores are commonly $19 \times 7\,\mu$, varying, however, from 12–24×5–$9\,\mu$. Formerly, it was suggested that this glœosporial form might be connected with *Gnomoniella circinata* (Fckl.) Sacc.

Klebahn in his investigations of this fungus ascertained that when the leaves are wintered over under suitable conditions of moisture an ascigerous stage is developed the following spring. This stage proved to be a Pseudopeziza; that is to say, a Pseudopeziza was one of the most abundant of the perithecial stages found on wintered leaves. The spores of other perithecial forms yielded upon inoculation of the growing leaves no result, whereas spores of the Pseudopeziza developed in due course of

FIG. 79. ANTHRACNOSE ON CURRANT LEAF. (Photograph by F. C. Stewart)

time the Glœosporial stage upon growing parts. The ascigerous stage develops as a small fungous body of rapidly growing tissue, completely immersed in the leaf, and more or less surrounded by the old hyphæ of the Glœosporial form. With further development the epidermis is ruptured and the apothecium opens as a fleshy disk-shaped structure, the basal portions of which consist of more or less pseudoparenchymatous tissue from which arise numerous asci and paraphyses. The basal portion remains in part surrounded by thick-walled cells of the old mycelium, as

shown in Fig. 80, *b*. The asci are club-shaped and bear eight hyaline ovoidal spores. The paraphyses are simple or branched, sometimes once-septate and slightly club-shaped.

This fungus shows in pure culture certain growth characteristics which seem to differentiate it somewhat sharply from other species of Glœosporium. In the first place it grows slowly upon nutrient agar, several months being required to produce a colony of several millimeters in extent. The hyphæ become considerably colored

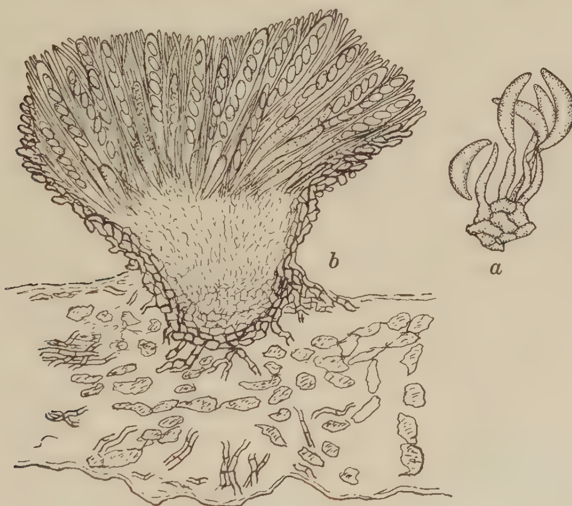


FIG. 80. *PSEUDOPEZIZA RIBIS.* (*b*, after Klebahn)
a, conidial stage; *b*, section of apothecium

and often gray-green in appearance. The central portion of the colony gradually forms a stromatic body. The cultures of the ascus stage yielded the same type of colony, which is further proof of the genetic connection between the two spore stages. This is the first time that a fungus with all the characteristics of a Glœosporium has been experimentally connected with an ascigerous form belonging to the Discomycetes.

XV. PHACIDIACEÆ

In this family the apothecium develops with a surrounding stroma, which is ordinarily coherent with the substratum. At

the outset the apothecium is closed, but opens by a circular or transverse split, and the edges are often torn or bent back as distinct lips or lobes. The apothecia are usually tough and leathery. The asci and paraphyses form a very closely adherent layer, in which the paraphyses overlap above the summit of the asci, forming a rather definite epithecium. Rhytisma is the only genus which is here of importance.

XVI. THE BLACK SPOT OF MAPLE

Rhytisma Acerinum (Pers.) Fr.

Klebahn, H. Bemerkungen über *Rhytisma acerinum* und über die Arbeit des Herrn. Dr. Julius Müller über die Runzelschorfe. Bot. Centrbl. **58**: 321–323. 1894.

Müller, J. Zur Kenntniss des Runzelschorfes und der ihm ähnlichen Pilze Jahrb. f. wiss. Botanik **25**: 607–627. *pls. 27–29.* 1893.

The black spot of the maple (Acer spp.) is a fungus of very wide distribution, but the amount of injury caused is so slight that it cannot be considered of much economic importance. The affected areas of the leaf are so conspicuous, however, as to attract the attention of all interested in parasitic fungi (Fig. 81). The fungus occurs upon a number of species of Acer, the first evidences of the spot being manifest by yellow, thickened areas soon after the leaves have attained full size. A cross section shows that beneath the cuticle there are produced in great quantity on short conidiophores arising from a stromatic tissue unicellular, curved conidia, and these conidia serve to spread the fungus, it is believed, during the same season. This stage is referred to the form genus Melasmia. The tough blackened structures, which appear in the affected spots as the season advances, consist in reality of sclerotioïdal masses of fungous tissue, black without but white within, penetrating all medullary parts of the leaf. These areas are much thicker than the normal leaf. After the fall of the leaf further growth or

Fig. 81. The Black Spot of Maple

differentiation takes place in the sclerotial areas, so that there is finally developed by the next spring rather unlimited, complex apothecia, often 1.5 cm. broad, which rupture by irregular fissures along the ridges of the wrinkled surface. The asci are club-shaped, and bear eight needle-shaped spores. Numerous paraphyses with incurved or hooked tips are present. The asci are $120–130 \times 9–10\,\mu$. At maturity the large spores ($65–80 \times 1.5–3\,\mu$) are ejected forcibly from the ascus, doubtless distributed by the wind, and they are provided with a mucilaginous membrane which, according to Klebahn, serves for adherence to the host. Artificial infection with ascospores has been effected, and after such infection the pycnidial stage may be produced within about eight weeks.

Among other common and conspicuous species of Rhytisma of wide distribution are *Rhytisma Salicinum* (Pers.) Fr. occurring on various species of Salix; *Rhytisma Vaccinii* (Schw.) Fr. on species of Ericaceæ, notably *Vaccinium arboreum* in the Appalachians.

XVII. PERISPORIALES

This order includes a few families well distinguished from the preceding Ascomycetes by the presence of a more or less membranous, generally spherical, closed fruit body, or perithecium, produced directly on the mycelium. In the two families which may here be considered, Perisporiaceæ and Erysiphaceæ, there is no mouth or ostiolum. The families may be distinguished as follows:

Perisporiaceæ. Mycelium generally dark in color; perithecium without differentiated appendages, and conidial stages not comparable to the form genus Oidium.

Erysiphaceæ. Mycelium generally hyaline; perithecium with appendages, often highly modified; and conidial stage, when present, invariably an Oidium.

XVIII. PERISPORIACEÆ[1]

This is a small family although some authors may include in it as many as twenty genera. The genera, as a rule, comprise

[1] The two genera which are here discussed have been included by Fischer (Engler and Prantl, *l. c.*) in the Plectascineæ, and there is considerable diversity of opinion as to their true position.

very few species. Some are parasitic and some saprophytic, some with superficial mycelium, and others with mycelium penetrating the substratum. Two genera which are important in this connection are Thielavia and Meliola. In the former genus the Mycelium is immersed in the host. The perithecia are membranous, without appendages, and subsidiary fruit forms include a stage with endogenous spores. In the genus Meliola, the mycelium is superficial and brown. The perithecia are beset with simple or branched appendages. The spores are brown and two-celled.

XIX. ROOT ROT OF TOBACCO, VIOLETS, PEAS, LUPINES, ETC.

Thielavia basicola (B. & Br.) Zopf.

BRIGGS, L. J. The Field Treatment of Tobacco Root-Rot. Bur. Plant Ind., U. S. Dept. Agl. Circular **7**: 1–8. 1908.

CLINTON, G. P. Root Rot of Tobacco. Conn. Agl. Exp. Sta. Rept. (1906): 342–368. *pls. 29–32.*

THAXTER, ROLAND. Fungus in Violet Roots. Conn. Agl. Exp. Sta. Rept. (1891): 166–167.

ZOPF, W. Ueber die Wurzelbräune der Lupinen, eine neue Pilzkrankheit. Zeitsch. f. Pflanzenkr. **1**: 72–76. *figs. 1, 2.* 1891.

This fungus, which is now known to cause in the United States, under certain climatic and soil conditions, a serious disease of tobacco (*Nicotiana Tabacum*), was first studied in Europe as a parasite of less consequence upon peas, lupines, etc. The morphology of the fungus and its relation to a disease of *Senecio elegans* was established in 1876. The fungus was found in the United States on violets (*Viola odorata*) in 1891, and subsequently on other plants; but in 1906 it was recognized in Connecticut as an important tobacco parasite.

Distribution. Upon one or more of its hosts the fungus has been found, in general, from Ohio eastward in the United States, and in western Europe from England to Italy. The fungus has not been reported from the southern states growing tobacco, or from tropical regions. It is believed that abundant moisture is essential for serious trouble by this fungus, lack of drainage and other factors assisting in producing this condition. Briggs has recently shown that the presence of this fungus in tobacco soils is an indication of alkalinity, a condition often brought about by the system of fertilization.

Host Plants. The following is a list of the natural hosts, as compiled by Clinton: Ginseng, *Aralia quinquefolia; Begonia rubra; Begonia* sp.; horse radish, *Cochlearia Armoracia; Cyclamen* sp.; lupines, *Lupinus albus, Lupinus angustifolius, Lupinus luteus*, and *Lupinus thermis; Nemophila auriculata;* tobacco, *Nicotiana Tabacum; Onobrychis Cristagalli;* pea, *Pisum sativum; Trigonella cœrulea;* and violet, *Viola odorata.* It is therefore evident that a variety of dicotyledonous plants may

FIG. 82. THE THIELAVIA DISEASE OF TOBACCO. (After G. P. Clinton)
Healthy and diseased root systems

be attacked. The leguminous hosts are, however, most numerous, and the fungus is quite frequent on garden and sweet peas.

Pathological effects. Roots affected by the Thielavia do not develop a normal root system, or they may be injured to such an extent that on pulling up an affected plant from a moist soil practically everything except a stub of a root will be broken off. In the case of the tobacco a cluster of new roots may form on the crown above the first injuries (Fig. 82). The fungus is apparently most injurious in the seed beds. Affected plants may not be killed, and many go through the season with a stunted growth, or with such a check upon vigorous development at the

outset as to cause manifest loss in the final crop. Again, diseased plants may entirely recover.

The surfaces of diseased roots may be roughened and browned by the presence of the fungus, but the tissues within are usually, in the case of violets, peas, etc., tinted red or pink. Ordinarily the fungus penetrates all parts of the rootlet, but as is common with plants which are not vigorous or obligate parasites, there are no abnormal cell divisions of the host.

Morphology of the fungus. The mycelium is intercellular, abundantly septate, and at first hyaline. The threads are narrow, and the branches are cut off by a septum at a slight distance from the main hypha, somewhat as in Rhizoctonia (*Corticium vagum*).

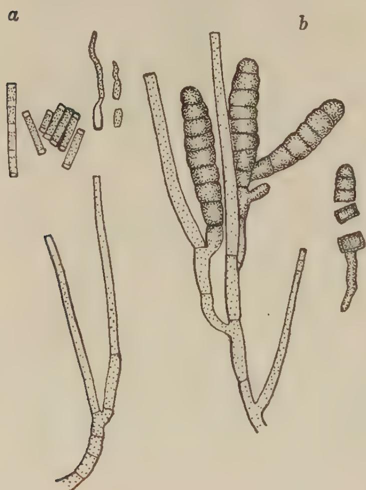


Fig. 83. Conidia and Chlamydospores of Thielavia

Three kinds of spores have been commonly found, namely, (1) endosporous conidia; (2) thick-walled conidia, or chlamydospores; and (3) ascospores.

1. The endospores are an interesting type of spores formed in chains in terminal branches or clusters of branches (Fig. 83, *a*). These spores are formed by basipetal septation as short cylindrical cells within the branch. The tip of the branch is finally broken and they are pushed out by osmotic force, the branch assuming the part of a spore case. The endospores are distinctly hyaline, and as produced in artificial cultures, they may remain united in short threads, or cohere laterally as small rafts. Individuals measure about $10\text{-}20 \times 4\text{–}5\ \mu$.

2. The chlamydospores are thick walled, more or less cylindrical, brown spores, borne in chains, the early stages of formation differing apparently only in size from the endospores. At maturity, however, the short chains, or rather the colored spore cells of these, break up, as shown in Fig. 83, *b*, measuring about $12\ \mu$ in width.

3. The perithecia bearing the ascospores are relatively simple. The asci are evanescent, and the spores unicellular, lenticular, vacuolate, and measure about $12 \times 5\ \mu$.

Artificial cultures are readily made on various media, and the first two spore stages may be quickly produced in culture, the endospores, particularly, being aërial. The association of the ascosporous stage with the others and the apparent continuity of mycelium are believed to show genetic connection.

Control. Since the seed bed is perhaps the greater source of trouble in the case of tobacco, sterilization of the soil where the disease has become established may be necessary. Diseased plants should not be used for planting. Thorough aëration of the soil by drainage and cultivation is also desirable. The suggestion that this fungus is constantly associated with an alkaline soil requires an investigation of the soil conditions with a view to correcting this by subsequent fertilization.

XX. SOOTY MOLD OF ORANGE

Meliola Camelliæ (Catt.) Sacc.

FARLOW, W. G. On a Disease of Olive and Orange Trees, occurring in California in the Spring and Summer of 1895. Bullt. of the Bussey Institution **5**: 404–414. 1876.

WEBBER, H. J. Sooty Mold of the Orange and Its Treatment. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **13**: 1–34. *pls. 1–5.* 1897.

Distribution and effects. The sooty mold is a disease which is probably distributed throughout all moist citrus-growing regions. It is perhaps most injurious upon the orange, but it occurs also upon the other cultivated citrous fruits. In one sense it is scarcely to be regarded as a fungous disease, since the fungus which produces the obnoxious effect is probably not parasitic. Nevertheless, the fruit infested by the sooty mold is seriously injured from the commercial standpoint, and since it is the fungus which effects this injury, it may justly be considered in this connection.

The sooty mold consists, as the name implies, of a sooty growth, or crust, which occurs both upon leaves and fruit. It may appear in isolated patches or investing practically the entire leaf or fruit surface. The black mass is made up entirely of fungous hyphæ. The fungus is only found following the attack

of certain scale insects. In Florida it commonly succeeds attacks by the white fly, or Aleyrodes. It is, however, in other localities equally as abundant following other species of aphid-like insects. The fungus has long been a nuisance in the Mediterranean orange groves, and for some years has been of sufficient abundance in both Florida and California to require control measures.

The fungus. The mycelium of the fungus consists of large branched threads which are at first olive green and velvety, becoming with age deep brown with a tendency to scale or break up into small patches. The hyphæ are closely septate, often consisting of chain-like groups of cells, readily separated one from another. Moreover, abundant branching and cementing together of these branches may give rise to a kind of false stratum or tissue; anastomosing also occurs. Careful microscopic examination has failed to disclose any penetration of the host by this organism, and it would appear that it utilizes as a source of nutriment only the so-called honeydew resulting from the presence of the insects referred to. Certain modified, knob-like branches of the hyphæ are commonly found, but it is apparent that these *hyphopodia* serve merely as organs of attachment.

The propagative stages of this fungus are numerous. Conidia of several types, stylospores in pustules, pycnidia, and perithecia may be present. The conidia may be simple cells abscised from upright hyphæ or they may be more highly differentiated compound structures. The stylospores are produced from small conidiophores, developed within peculiar, elongate, flask-shaped structures. These form a conspicuous part of the fungus and are present throughout a considerable period of its growth. They are particularly evident when branched or variously subdivided, or adherent in groups. The pycnidia are relatively minute, but they occur in considerable number distributed over the entire surface. The spherical perithecia are somewhat larger than the pycnidia and, like those of other members of this family, are closed bodies which disseminate their spores only upon disintegration. The perithecium may contain several short, stout asci with eight dark, elliptical, three-to-four septate spores. With the diverse sorts of spore forms mentioned, it will be evident that the fungus is rapidly distributed, and consequently spreads with alarming facility under favorable conditions.

Control. A thorough study of effective methods of control has been made under conditions in Florida, and it has been found that the most effective preparation there tested is the resin wash. This mixture consists, according to Webber, of the following ingredients:

Resin	20 lb.
Caustic soda, 98 per cent	4 lb.
Fish oil, crude	3 lb.
Water to make	15 gal.

He prepares this mixture as follows: Place the resin, caustic soda, and fish oil in a large kettle. Pour over them 13 gallons of water, and boil until the resin is thoroughly dissolved, which requires from three to ten minutes after boiling has commenced. While hot add enough water to make just 15 gallons. It is advised to make about two sprayings when the insect is in the larval stage. In Florida, winter sprayings are important, but a spraying in May is also often desirable. In all cases dilute the stock solution with 9 parts of water.

XXI. ERYSIPHACEÆ

BURRILL, T. J., and EARLE, F. S. Parasitic Fungi of Illinois. Ill. State Lab. Nat. Hist. **2**: 387–432. 1887.

DE BARY, A. Beiträge zur Morphologie u. Physiologie der Pilze **1** (13–14): 23–75. *pls. 9–12.*

HARPER, R. A. Die Entwickelung des Peritheciums bei Sphaerotheca Castagnei Ber. d. deut. bot. Ges. **13**: 475–481. *pl. 39.* 1895.

HARPER, R. A. Sexual Reproduction and the Organization of the Nucleus in Certain Mildews. Carnegie Institution of Washington. Publ. **37**: 104. *7 pls.* 1905.

NEGER, F. W. Beiträge zur Biologie der Erysipheen. Flora **90**: 221–272. 1902.

REED, G. M. Infection Experiments with Erysiphe graminis De C. Trans. Wis. Acad. Sci., etc., **15**: 135–162. 1905.

REED, G. M. Infection Experiments with the Mildew on Cucurbits, Erysiphe Cichoracearum De C. Trans. Wis. Acad. Sci., etc., **15**: 527–547. 1907.

SALMON, E. S. A Monograph of the Erysiphaceæ. Memoirs of the Torrey Bot. Club **9**: 292 pp. *9 pls.* 1900.

SALMON, E. S. Further Cultural Experiments with Biologic Forms of the Erysiphaceæ. Ann. Bot. **19**: 125–148. 1905.

SANDS, M. C. Nuclear Structures and Spore Formation in Microsphæra Alni. Trans. Wis. Acad. Sci., etc., **15**: 733–752. *pl. 46.* 1907.

SMITH, GRANT. The Haustoria of the Erysipheæ. Bot. Gaz. **29**: 153–184. *pls. 11, 12.* 1900.

This is a family which, according to the most recent monograph, includes forty-nine species and eleven varieties of fungi,

commonly known as mildews, powdery mildews, and blights (Germany, Mehltau; France, blanc, etc.). Some writers would make more than a hundred species of the various forms, the species being determined very largely by the hosts upon which they occur. The Erysiphaceæ are all strictly parasitic, producing a considerable, septate, superficial mycelium with a single form of conidial spore and a closed perithecium containing the asci. This family is such a homogeneous, coherent group that it may be treated as a whole, and subsequently a few notes on particularly important species may be made.

Geographical. The various members of this family are, generally speaking, most abundant in the north temperate regions of the earth, but as a family they are not limited in their distribution. Moreover, one species is known to occur as far north as Greenland, while another is found in Terra del Fuego. The number of species common to America, on the one hand, and to Europe, Asia, and Africa, on the other, is approximately the same; but there are supposedly more endemic forms in America than in all other countries. Salmon gives fourteen endemic species with five varieties for America, while only thirteen species and four varieties are known to be endemic in Europe, Asia, and Africa combined.

Climatic relations. The distribution of these fungi is apparently not closely restricted by slight climatic differences. A certain amount of moisture is unquestionably essential to the vigorous production of the superficial mycelium characteristic of this group, and there are fewer species in dry, exposed regions, as, for instance, in the Great Plains regions of the United States, than in the more moist Appalachian region. Nevertheless, there are a number of species that may be found from the extreme north to the extreme south, as well as from east to west in both the eastern and western continents. Climatic conditions, especially, may determine whether or not a particular species may become a devastating disease-producing organism or may be classed merely as a fungus of occasional economic importance. *Erysiphe graminis*, for instance, is seldom a fungus of any consequence in most sections of the United States, while in England it may at times cause serious injury to cultivated grasses.

Host plants. The various species and varieties of mildew have been reported upon about fifteen hundred species of phanerogams. The list of hosts includes plants of numerous orders and families. A few notable exemptions among plants of normal terrestrial habits are Liliaceæ, Iridaceæ, and some other monocotyledons. Furthermore, there are many exceptions among such families, for instance, those having the habit of growing under unusually moist conditions. Moreover, herbs, shrubs, and trees are more or less equally affected, and sometimes a single species of these mildews may be found upon plants of all three sorts.

The leaves are usually the chief parts affected, although some species may attack also the twigs, stems, and fruits. As a rule, those having the densest mycelia are more persistent and more likely to infest all portions of the plant. The Erysiphaceæ seldom cause conspicuous distortions of the host plant. The anatomical modifications are therefore secondary in interest to the physiological effects.

Cross inoculations. In a very recent summary of the general results of cross inoculation in the mildews, Reed states :[1]

One or more species of five of the genera of the Erysiphaceæ have been tested for their capacity for infecting host plants other than the one from which they came. Podosphæra is the only genus which thus far has not been tested. With reference to four genera, Microsphæra, Sphærotheca, Phyllactinia, and Uncinula, the data are very meager. The bulk of the work has been done with three species of Erysiphe, — *E. Cichoracearum*, *E. graminis*, and *E. Polygoni*. Even with these species the number of trials is very small in many cases, the evidence often resting on a single experiment. Still, sufficient data have been accumulated to form the basis of certain at least tentative general conclusions.

So far as investigated, the mildew on the cucurbits, *Erysiphe Cichoracearum* D. C., is the only one which is shown to be capable of infesting plants belonging to more than one genus. My results with this mildew are based on a large number of trials, many of them repeated at different times during three years, and cannot be questioned.

There are other cases where the mildew is limited closely to plants of a single genus. For example, the mildew on rye is limited to species of the genus Secale. The same is true with reference to the bluegrass mildew on species of Poa.

Several cases also are recorded where the mildew from one species will not infect other species of the same genus. Most of these claims, however, rest on

[1] Reed, Geo. M. Infection Experiments with Erysiphe cichoracearum DC. Univ. of Wisconsin Bullt. **250** : 340–416. 1908.

insufficient data. The evidence is more conclusive with reference to the mildew on species of Hordeum and also the one on the Brome grasses. Salmon . . . has investigated both of these. The mildew on barley (*Hordeum vulgare*) will infect this species and also *Hordeum distichum*, *H. decipiens*, *H. Hexastichum*, *H. intermedium*, and *H. Zeocriton*, but will not pass over to *Hordeum jubatum*, *H. bulbosum*, *H. murinum*, *H. secalinum*, *H. sylvaticum*. In some of these cases, however, the number of trials is very small.

Morphological. With only one or two exceptions (notably *Sphærotheca Mors-uvæ*) the superficial mycelium of these plants consists of colorless hyphæ, considerably septate, each cell being ordinarily uninucleate. In all species except two, so far as is known, the haustoria penetrate the epidermal cells in the form of short, swollen branches. However, in one common mildew of shrubs and trees (*Phyllactinia Corylea*) hyphal branches grow through the stomata and into the intercellular spaces. These branches may in turn develop haustoria, which enter the cells in contact with this intercellular hypha. As a rule conidial production in all forms begins whenever a considerable mycelium has been developed. These conidia consist, quite generally, of a single chain of cylindrical or more or less barrel-shaped unicellular portions produced in basipetal order on short, erect conidiophores, developed directly from a hyphal cell. The conidia are capable of immediate germination, and since they are produced in quantity, they frequently give the mealy or powdery appearance to the parts affected. They serve for the rapid propagation of these fungi. The conidial stage was for a long time unconnected with the perithecium form and was then known under the form-generic name Oidium. The minute characteristics of the oidial stages have not been sufficiently studied. It is proper to use the name Oidium for any conidial form the perfect stage of which is unknown or indetermined.

FIG. 84. HABIT OF A POWDERY MILDEW

Perithecia are usually developed during the middle or latter part of the growing season. They are produced directly upon the mycelium, and the development is interesting and instructive. The development, however, can be best followed only by serial sections of properly imbedded material. In brief, it may be described as follows: Two adjacent cells or hyphæ give rise to erect branches, one of which is larger and may be designated as the oogonium, the other, smaller branch as the antheridium. After a basal cell is cut off in each case, and further, a terminal antheridial cell in the one case, there is dissolution of a portion

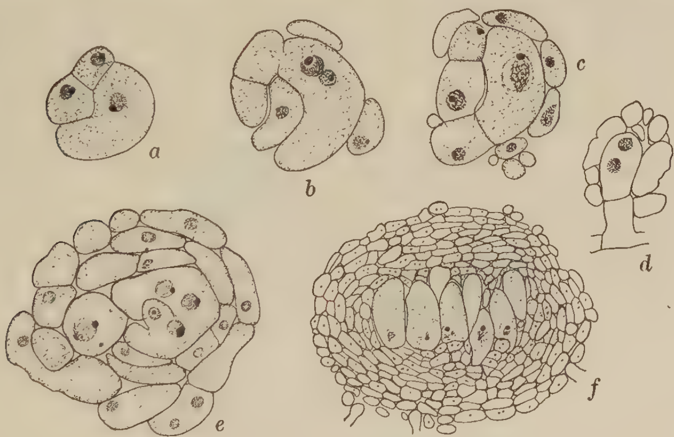


FIG. 85. *PHYLLACTINIA CORYLEA:* GAMETES, FERTILIZATION, AND DEVELOPMENT OF PERITHECIUM AND YOUNG ASCI. (After Harper)

of the wall between the antheridium and the oogonium, migration of the antheridial nucleus, and fusion of this with the oogonial nucleus (Fig. 85, *b*). Subsequently the oogonial cell undergoes several divisions. The last cell but one in this ascogonium contains always two nuclei, and these fuse prior to the development of this cell as an ascus. This is the case when a single ascus is produced, and it is only slightly more complex when many asci result (cf. Fig. 85, *d-f*). Following the fusion of the two gametic nuclei, hyphal branches arise from the stalk cell of the oogonium. These converge around the oogonium and finally completely inclose it. Within this first layer a second layer of hyphæ is produced in similar manner; and subsequently, by outgrowths from each of

these layers into all available space, smaller hyphæ are protruded; thus a compact inclosing body or perithecium is developed. With the further growth of the perithecium and the increase in size of the ascus, the inner layer and all internal hyphal branches are dissolved and appropriated. Meanwhile, the outer layer becomes yellow or brown and forms the true wall of the perithecium. From the wall cells of the perithecium there are

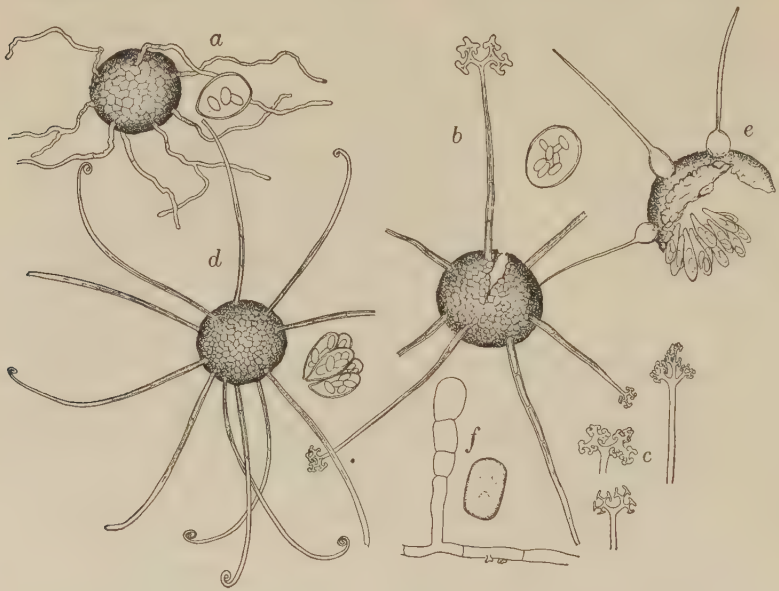


FIG. 86. SPORE FORMS AND APPENDAGES OF ERYSIPHACEÆ

a, *Erysiphe Polygoni*; *b*, *Podosphæra Oxyacanthæ*; *c*, *Microsphæra Alni*; *e*, *Phyllactinia Corylea*; *d* and *f*, *Uncinula necator*

produced, either from the base or from a more or less equatorial plane, the characteristic appendages. In a few cases only are appendages produced from the apex. At maturity there are one or more asci, depending upon the genus, and each ascus contains normally from two to eight spores, the shape of the ascus varying from practically spherical in the one-ascus forms to clavate or cylindrical where there are two or many asci. The spores are one celled and colorless. As a rule the ascospores do not germinate immediately, requiring a period of rest. By

the following spring the perithecia are very brittle and are said to break open forcibly in water, after which time the ascospores readily germinate. The appendages of the perithecium are very different in structure from the mycelium in general. The thick walls, rigidity of the cells in most genera, and peculiar branching indicate that they are specialized structures, and they doubtless have an importance in relation to the support of the perithecium or the dissemination of this body.

Classification. The generic subdivisions are based upon the number of asci in the perithecium and upon the form and method of branching of the appendages. The following key will indicate the chief generic characters:

A. Perithecia contain a single ascus.
- 1. Appendages simple, flexuous, and undivided at the tip. . . . . *Sphærotheca*
- 2. Appendages once or more dichotomously divided at the tip. *Podosphæra*

B. Perithecia containing several to many asci.
- 1. Appendages never more than slightly swollen at the base.
  - *a*. Appendages simple or more or less flexuous, or irregularly branched, mycelial-like; without tip peculiarities. . . . . *Erysiphe*
  - *b*. Appendages usually straight, once or more dichotomously branched at the tip . . . . . *Microsphæra*
  - *c*. Appendages usually straight and spirally inrolled at the tip . . . . *Uncinula*
- 2. Appendages swollen at the base so as to form an enlarged plate. *Phyllactinia*

XXII. THE GOOSEBERRY MILDEW

Sphærotheca Mors-uvæ (Schw.) B. & C.

CLOSE, C. P. Treatment for Gooseberry Mildew. N. Y. (Geneva) Agl. Exp. Sta. Bullt. **161**: 153–164. *pls. 1–2.* 1899.

ERIKSSON, J. Der amerikanische Stachelbeermehltau in Europa, seine jetzige Verbreitung und der Kampf gegen ihn. Zeitsch. f. Pflanzenkr. **16**: 83–90. 1906.

SALMON, E. S. On the Present Aspect of the Epidemic of the American Gooseberry Mildew in Europe. Journ. Roy. Hort. Soc. **29**: 102–110. *fig. 23.* 1905.

This species has long been known as the cause of an important disease of gooseberries in the United States. It occurs

upon the leaves and stems, but particularly upon the berries of the host, and it may sometimes cause injury to currant bushes. The mycelium is more persistent than that of most Erysiphaceæ. It is one of the few forms the mycelium of which becomes buff

FIG. 87. GOOSEBERRY MILDEW. (After Close)

or brown and thick-walled with age. The mycelium forms dense circular or effuse patches, sometimes completely covering a berry and the adjacent twig.

The perithecia are imbedded in the dense mycelium. They average about 80–100 μ in diameter and are beset with a few light brown, tortuous appendages. A single subglobose ascus

contains relatively large spores. According to Salmon this species is indistinguishable from the Sphærotheca found in Europe upon Euphorbia. The latter is, however, not very common in Europe. During the summer of 1906 a serious outbreak of gooseberry mildew was reported in Europe. The fungus has spread rapidly, and the result of this outbreak will undoubtedly afford European

Fig. 88. Mildew of Peach on Nursery Stock

investigators an opportunity of testing the validity of the above opinion.

Control. The American gooseberry mildew is one of the most difficult of the mildews to control. English varieties of gooseberries in America have proved most susceptible, and the best results have been obtained by the use of a spray of relatively strong potassium sulfide, — 1 ounce to 2 gallons of water. Spraying should be given from the time that the buds break open, and

where the fungus promises to be abundant, it may be necessary to repeat the spray every ten or twelve days. Recently it has been reported that sulfuric acid may be used to advantage in the treatment of the rose mildew, the strength employed being 1 part of strong acid to 1000 parts of water. This preparation should prove serviceable, but it has not been tested for the gooseberry mildew. Winter treatment with a lime-sulfur wash has been considered desirable as a result of some Canadian experiments.

XXIII. MILDEW OF PEACH. ROSE MILDEW

Sphærotheca pannosa (Wallr.) Lév.

SMITH, ERW. F. Peach Mildew. Journ. Mycology **7**: 90–91. 1892.
WHIPPLE, O. B. Peach Mildew. Colo. Agl. Exp. Sta. Bullt. **107**: 1–7. *pls. 1, 2.* 1906.

This mildew bears the relation to the peach that *Podosphæra leucotricha* bears to the apple, that is, it is more commonly found on nursery stock, and then usually only when the conditions are moist and the stock crowded, although occasionally it occurs on mature trees (Figs. 88 and 89).

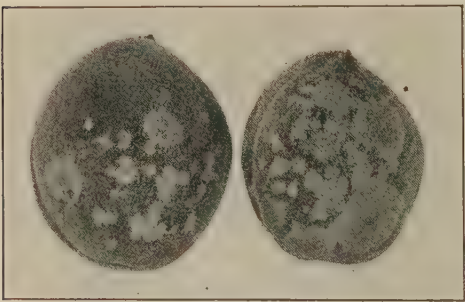


FIG. 89. MILDEW ON PEACHES

It is as a disease of cultivated roses that this fungus is best known, and most destructive. It is widely distributed and indeed absent from very few home gardens. There is great difference in the susceptibility of different varieties of the rose, and selection should lead to resistant strains in many cases. The crimson rambler is notably sensitive.

This mildew covers the leaves, especially the young leaves and the vigorous and young shoots, injuring and often arching or curling the leaves and deforming the more succulent stems. The oidial stage is produced in great profusion, and consequently the disease spreads rapidly. Perithecia are not always present.

Following a moist early summer I have found the perithecia abundant on old leaves in the shade during a very dry period in late summer (Fig. 90).

Control. Thorough dusting with flowers of sulfur every ten days is often sufficient. Ammoniacal copper carbonate is also effective.

Fig. 90. Rose Mildew, Perithecia Present

Sulfuric acid 1 to 1000 has recently been recommended. No experiments have been reported respecting the use of the "self-cooked" lime-sulfur for the rose mildew, but there is reason to believe that it may be far more effective than sulfur in this case.

XXIV. MILDEW OF APPLE AND CHERRY

Podosphæra Oxyacanthæ (De C.) De Bary

FAIRCHILD, D. G. Experiments in Preventing Leaf Diseases of Nursery Stock. Journ. Mycology **7**: 256. 1894.

This fungus is common on a large number of rosaceous and other plants, including apples, plums, thorn apples, etc. It may

FIG. 91. *SPHÆROTHECA HUMULI* ON CULTIVATED STRAWBERRY
(Photograph by E. H. Favor)

be considered as a destructive disease in this country chiefly as it occurs upon apple nursery stock or upon the cherry (Fig. 92). Upon the young apple plants the mycelium is rather dense and persistent. Perithecia are from 65 to 90 μ in diameter and the appendages, from 4 to 30 in number, are usually from 1 to 5 times as long as the diameter of the perithecia. Throughout about half of the length of the appendages they are dark brown in color, and they are also several times dichotomously branched at the tip. A single ascus is given as 58 to 90 by 45 to 75 μ, containing normally 8 spores. It is believed that the injurious action of this fungus may be easily prevented by the use of copper sprays.

Podosphæra leucotricha (Ell. and Ev.) Salm. In nurseries of New York and other eastern states this fungus has, during moist

seasons, given trouble of serious nature, particularly where the nursery stock are planted very close together. The mildew covers both surfaces of the leaves and frequently involves the whole twig. Spraying with Bordeaux mixture and potassium sulfide is effective.

XXV. POWDERY MILDEW OF PEAS

Erysiphe Polygoni De C.

This fungus is distributed throughout the world. It is the most common and one of the most variable of the Erysiphaceæ. The species has been listed upon considerably more than three hundred hosts of diverse genera and orders. Among these the succulent and herbaceous plants predominate, but the fungus occurs upon some woody hosts.

FIG. 92. MILDEW OF CHERRY

As a mildew of garden peas (*Pisum sativum*) this fungus may become a nuisance, especially when an attempt is made to grow these plants during the late summer. It is most prevalent during moist seasons, and more destructive in some Atlantic and southern states. Upon this host the fungus forms a rather dense, persistent mycelium, frequently covering stems, leaves, and pods. The conidia are developed in profusion. The perithecia, averaging 90 μ in diameter, are also produced in large number during a later period, commonly after the plants have begun to dry up. When the mildew attacks young plants the crop is generally a total loss. The fungus also attacks beans and certain vetches.

The perithecia contain ordinarily 6–8 asci, each with 2–3 spores. The appendages are very variable, even upon the same host, under similar conditions.

XXVI. MILDEW OF COMPOSITES AND OTHER PLANTS

Erysiphe Cichoracearum De C.

This species of mildew is also widely distributed and occurs upon more than two hundred hosts of numerous families. It is unusually common upon species of Compositæ and in general is easily the most destructive fungus of these hosts. It is also well known to the florist upon species of phlox and to the gardener upon some varieties of cucurbits.

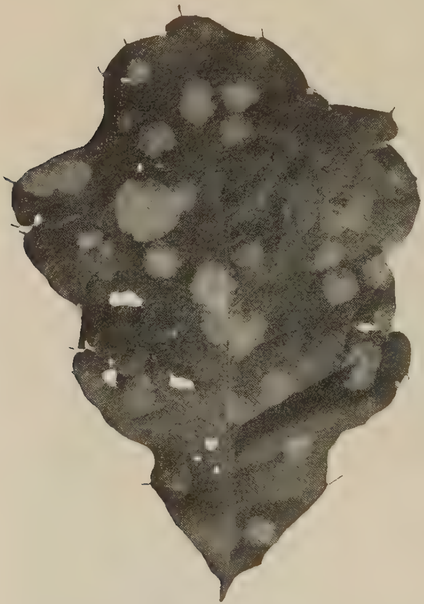


FIG. 93. *MICROSPHÆRA ALNI*, PERSISTENT FORM ON OAK. (Photograph by Geo. F. Atkinson)

The fungus is often confused with the previous species. The perithecia are about equal in size, but the appendages of this form are usually short. The asci are numerous (often 10–15), and Salmon considers that the central specific character lies in the possession of two spores. Nevertheless, this species is also variable in every character, and it will not be easy to distinguish morphologically between certain forms of the two species.

XXVII. MILDEW OF WOODY PLANTS

Microsphæra Alni (Wallr.) Wint.

This variable species is typically a fungus of a variety of woody plants. It is common upon amentiferous trees and shrubs, but popularly is doubtless best known as the lilac or syringa mildew. Upon the lilac the mycelium covers the entire leaf. So constant is its occurrence upon this host during the late

summer in the United States that one unconsciously associates with the lilac, during that season, a grayish color. Upon some hosts, however, the mycelium may form persistent patches (Fig. 93).

The perithecium is generally small, with appendages averaging $1\frac{1}{2}$ times its diameter. These are colorless to light brown in part, and 3 to 6 times dichotomously branched. The asci are usually 3–8, each containing 4–8 relatively small ($18–23 \times 10–12\,\mu$) spores.

XXVIII. POWDERY MILDEW OF GRAPE

Uncinula necator (Schw.) Burr.

BIOLETTI, F. T. Oidium or Powdery Mildew of the Vine. Calif. Agl. Exp. Sta. Bullt. **186**: 315–352. *figs. 1–17.* 1907.
GALLOWAY, B. T. Observations on the Development of Uncinula spiralis. Bot. Gaz. **20**: 486–491. *pl. 32–33.* 1895.
VIALA, P. Les maladies de la vigne, *l. c.*, 2–56. *pl. 1. figs. 1–19.* 1893.

This mildew is one which has long been known as an important fungous disease in Europe and in America. For many years it was supposed that the American plant might not be the same as the European, since in the latter country only the oidium stage was known, that stage having been described as *Oidium Tuckeri* Berk. It is now certain that the plant in the two countries is the same species.

This species has a light mycelium, which develops on both sides of the leaves and sometimes on the flower clusters. In the United States it is especially abundant on the leaves in moist situations during the late season. It produces a mottled and slightly arched condition. During some seasons considerable injury results to the plant. The conidia are produced in abundance and the disease may be rapidly spread. The perithecia vary from 70 to $128\,\mu$ in diameter and are provided with a varying number of appendages, usually from 10 to 20 or more, each appendage being from one to four times as long as the diameter of the perithecium. These appendages are straight or slightly flexuous, except as to the uncinate or incurved tip. They may be septate, and amber brown in the lower half. There are usually 4–6 asci, each containing 4–7 spores.

It is difficult to explain the absence of the perithecial stage for so long a period in Europe, and even now when many observers would be alert to the presence of such a form, it is certain that the occurrence of perithecia is exceptional. For a long time it was supposed that the disease was imported to Europe from America, as were other grape diseases, but since the fungus is also found in Asia, there is no special reason for this assumption. The use of the more common fungicides has not been so successful in preventing the attacks of this fungus as the simple sulfur dust treatment.

XXIX. POWDERY MILDEW OF WILLOW AND POPLAR

Uncinula Salicis (De C.) Wint.

This species is apparently limited in host plants to the two genera Salix and Populus, but it occurs upon many species of these throughout their distribution. The mycelium occurs on both surfaces, frequently evanescent on poplars, while often persistent and in patch-like areas on willow, or covering the entire surface (Fig. 94). On the latter the perithecia are also generally aggregated. They average 135 μ in diameter, and are provided with numerous (often more than 100) hyaline appendages, the tips of which are distinctly uncinate. The asci are generally about 10, with 4–6 spores, measuring 20–26 × 10–15 μ.

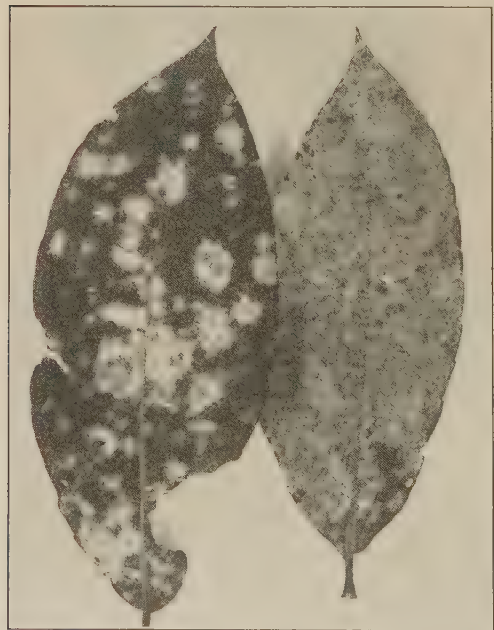


FIG. 94. POWDERY MILDEW OF WILLOW. (Photograph by Geo. F. Atkinson)

On the willow the area occupied by the mycelium sometimes shows a tendency to retain its chlorophyll longer than other portions of the leaf. This stimulating effect of a parasite is, however, best marked in the case of *Uncinula Aceris* (De C.) Wint., occurring on several species of maple (Acer). The yellow leaves in the late autumn may show definite green areas, which will be found to be the parts of the leaf occupied by the fungus (Fig. 95).

XXX. COMMON MILDEW OF TREES

Phyllactinia Corylea (Pers.) Karst.

Palla, E. Ueber die Gattung Phyllactinia. Ber. d. deut. bot. Ges. **17**: 64–72. *pl. 5.* 1899.

Salmon, E. S. On Certain Structures in Phyllactinia. Journ. Bot. **37**: 449–454. *pl. 402.* 1899.

This species of mildew is so distinct from those previously discussed that it is by some made the type of a subfamily. As previously stated, no haustoria are present, but special seta-like branches penetrate the host. The perithecium is large and provided with hyaline, rigid, acicular appendages, each with a swollen base. There are many asci, containing 2 or 3 spores (Fig. 86, *e*). The development of the asci has been discussed (Fig. 85).

Fig. 95. Yellow Leaf of Maple, with Green Areas occupied by Uncinula

This species occurs more commonly upon shrubs or trees, but it is also parasitic upon a limited number of herbaceous plants. It is known to be distributed throughout the northern hemisphere, and is frequently one of the more common of the surface mildews.

XXXI. HYPOCREACEÆ

In this family the mycelium is light or bright colored, never dark, as is also the stroma when present. Perithecia are also colored and vary from a buff or yellow to brown, red, or purple, never black. They are usually more or less flask-shaped, free upon the substratum, borne upon a mycelial weft (subiculum), upon a stroma, or imbedded partially or completely in a stroma (well-differentiated perithecial walls are absent in Claviceps, etc.). The perithecium possesses a distinct ostiolum or mouth. The asci are cylindrical or clavate fusiform. The spores (usually eight) are diverse in form, and they sometimes bud within the ascus. Paraphyses may be present. In general, the family is distinguished from other pyrenomycetes only by color and texture.

In this large family important pathological forms may be selected from three genera, — Neocosmospora, Nectria, and Claviceps.

In Neocosmospora there is no true stroma. The colored perithecia (buff or yellow to red) are clustered or scattered. They possess pseudoparenchymatous walls and rather long ostiola. The asci contain eight spherical, brown spores, with a distinctly wrinkled surface. Conidia are present.

In the genus Nectria the perithecia are yellowish to brown or red, single or grouped, even varying as to the extent of the stroma, which is, however, usually tuberculate or wart-like. The asci are mostly cylindrical, bearing eight 1-septate, usually hyaline, elliptical spores. Conidia are common.

Claviceps is characterized by the development of definite stromata (sporophores) from a relatively large sclerotium, a stroma consisting of a sterile stalk and a fertile head. Within the latter (peripherally disposed) the asci are contained in flask-shaped structures. There is no definite perithecial wall surrounding the ascal conceptacle. The asci are more or less cylindrical and bear eight hyaline, continuous, needle-shaped spores.

Closely related to Claviceps may be mentioned the genus Cordyceps, including some interesting and striking forms. The majority occur upon insects, upon which they are parasitic or saprophytic. Two species are more or less common parasites of Elaphomyces, a truffle-like, hypogeous genus.

XXXII. WILT DISEASE OF COTTON, COWPEA, AND WATERMELON

Neocosmospora vasinfecta (Atkinson) Erw. Smith

ATKINSON, GEO. F. Some Diseases of Cotton. III. Frenching. Ala. Exp. Sta. Bullt. **41**: 19–29. 1892.
ORTON, W. A. The Wilt Disease of Cotton and its Control. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **27**: 1–16. *pls. 1–14.* 1900.
ORTON, W. A. The Wilt Disease of the Cowpea and its Control. Bureau of Plant Industry, U. S. Dept. Agl. Bullt. **17**: 1–20. *pls. 1–4.* 1902.
SMITH, ERW. F. Wilt Disease of Cotton, Watermelon, and Cowpea. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **17**: 1–53. *pls. 1–10.* 1899.

This is a fungous disease which has become prominent only during the past fifteen years, and it is already a serious foe. The

FIG. 96. EFFECTS OF THE COTTON WILT FUNGUS IN A FIELD OF NON-RESISTANT COTTON. (Photograph by W. A. Orton)

fungus has been studied extensively both in its general biological and also in its cultural relationships, but it is not yet certain that the forms on the different host plants are properly referable to the same species. If so, however, it would certainly seem that these hosts have caused at least a racial variation in the parasite.

Distribution. The wilt disease of cotton is now known to be one of the most destructive parasitic diseases of this crop, and it is probable that the fungus is distributed practically throughout

the cotton-growing states. It has, however, been found as a most serious malady in portions of South Carolina, particularly on the sea islands, also in many localities of Georgia, Alabama, and Louisiana. It exists also to less extent in other southern states, and as far west as Arkansas. The writer has not observed it in Texas, although points in all parts of the state were visited in 1900 and 1901. On the watermelon the fungus has also been found in much the same territory, but most abundant in Virginia and South Carolina. The cowpea is affected in many southern states.

Fig. 97. A Cotton Field Contiguous to that in Fig. 96, but planted to a Resistant Strain of Cotton. (Photograph by W. A. Orton)

Climatic relations. The wilt diseases do not appear to be to any great extent dependent upon climatic conditions. The fungus, as will be shown later, is normally to be found in the soil, where it may perhaps exist saprophytically for indefinite periods. Neither severe temperature changes nor general differences in soil conditions seem to be of special consequence. Plants in sandy regions may be more readily wilted than those in soils more retentive of moisture, but, at the same time, the fungus evidently does no greater damage ultimately in one soil than in the other.

Parts of the plant affected. The wilt disease of cotton was first described as a "Frenching" (Atkinson). Cotton plants in

the heavy soils of central Alabama were somewhat peculiarly affected by this fungus. There is first a yellowing and finally a drying out of those portions of the leaves farthest from the main fibrovascular bundles, that is, between the lobes. Later such leaves might fall, or the whole plant might become wilted, and finally brown and dead. In other regions of the country the "wilting" is much more a characteristic appearance, — the disease being scarcely noticeable, except in a stunted condition of the plants, until finally wilting results. In general, the disease

Fig. 98. Cotton Plants of the Same Age: to the Left, Healthy; to the Right, affected by Wilt. (Photograph by W. A. Orton)

is typically that of a wilt in the case of both cowpeas and watermelons. The affected plants have therefore the appearance which any plant would have when deprived of its water supply, that is, a general wilting and drying up. On cutting the stem, or even the leaf petiole of affected cotton, a darkening of the xylem portion of fibrovascular bundles is shown, and this is an excellent indication of the presence of this fungus, since no other disease now known discolors the xylem in this way. In some cases plants affected and dwarfed show little or none of the characters in the stem, yet an examination of the larger root branches and even the tap root would show the characteristic appearance. In

spite of the fact that the disease may sometimes be suddenly manifested, yet it is certain that it has a long period of incubation, and works very slowly, the final killing of the plant being effected only when its water supply is almost completely cut off by the filling of almost all of the vessels with the fungous hyphæ.

Resistance of the varieties of the hosts. In almost any infested field it will be noticed that there are plants of different degrees of resistance toward this fungus. In some plants the fungus is only able to effect an entrance into the roots, and each point of infection may be the point of origin of several rootlets developed in the form of a small tuft. Again, the fungus may extend practically throughout the root system and yet fail to invade the stem. Finally, the whole plant may sometimes be affected. Two plants in the same hill may show great diversity in this relationship. Therefore it may be said that all degrees of resistance may be found. Experiments conducted by planting many varieties across land known to be infected by the disease have shown interesting racial variations. Special resistance has been shown by some of the Egyptian cottons, although they are not in any case wholly resistant. On the other hand, sea island cotton is particularly susceptible to this fungus. The most resistant of the upland cottons thus far reported are certain strains of the variety known as Jackson, a limbless sort. The following interesting table (Orton) was prepared in 1900:

Table showing Varietal Resistance of Cottons to the Wilt Disease

(The figures denote the comparative resistance of the different races on a scale of one thousand.)

Variety	Resistance	Variety	Resistance
Jannovitch	565	Brady	127
Mitafifi (average of 3 strains)	559	Cook's Long Staple	124
Abbasi	479	Excelsior	104
Jackson (one strain)	453	Drake	90
Sea Island	233	Jones	88
Eldorado	227	King	83
Texas Wood	162	Peterkin	71
Doughty	148	Truitt	71
Hawkins Prolific	142	Russell	55

In the same way as for the cotton, so also in the case of the cowpea, resistant races have been found. The most resistant of the original varieties tested was the form known as Iron Mountain, which has since been considerably crossed, and in various ways improved.

The fungus. It has been stated that this fungus is unquestionably very generally distributed and may live indefinitely in the soil. This is due to the fact that it is easily propagated in a saprophytic manner and may therefore live in all probability a long period of time without the intervention of the parasitic habit. The fungus gains entrance to the host through the soil,

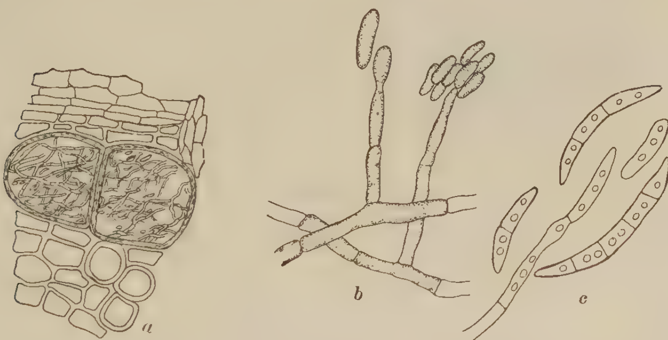


FIG. 99. *Neocosmospora vasinfecta.* (*c* after Erw. F. Smith)
a, the fungus in xylem of stem; *b* and *c*, conidial stages from cultures

and hence through the root system. This is believed to be the sole method of infection with the form on cotton and cowpea. It is also believed that healthy plants are directly affected without the assistance of any other organism or mechanical effect causing an injury through which the fungus might obtain access. The mycelium of the plant is at first found most abundantly in the vessels of the xylem (Fig. 99, *a*); but in later stages of the disease it may pervade other tissues. Upon the death of the plant it comes to the surface along the lines of least resistance; hence it appears lineally distributed in the areas between the vertical lines of bast. The fungous hyphæ are, as they occur in the host plant, yellowish in color, considerably septate, and irregularly branched. According to Atkinson conidia may be

formed within the vessels. These conidia, frequently spoken of as microconidia, are at first cylindrical or elliptical, and without septa; but they may become slightly curved and once or twice septate. These are capable of germination and growth within the tissues. On the surface of the host and in culture a type of conidia known as macroconidia may be produced in quantity. These are lunulate or crescent-shaped and from three to five times septate, measuring $30–50 \times 4–6\,\mu$ (Fig. 99, *c*). Upon the host the conidiophores arise in loose stromatic tufts known as sporodochia. In culture all gradations between the small and large conidia may be observed. Moreover, an oidium-like stage is sometimes produced, and in the race of this fungus on the melon chlamydospores are not uncommon in old cultures.

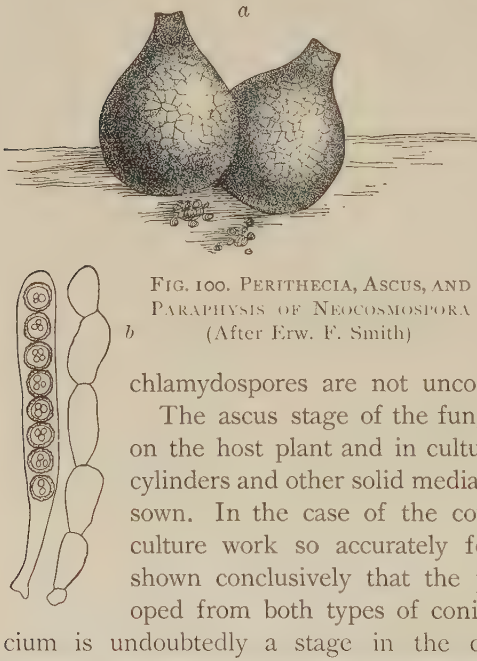


FIG. 100. PERITHECIA, ASCUS, AND PARAPHYSIS OF NEOCOSMOSPORA (After Erw. F. Smith)

The ascus stage of the fungus has been found both on the host plant and in cultures upon steamed potato cylinders and other solid media in which ascospores were sown. In the case of the cowpea fungus the line of culture work so accurately followed out (Smith) has shown conclusively that the perithecia may be developed from both types of conidia and that the perithecium is undoubtedly a stage in the development of the wilt fungus. As the fungus shows considerable differences on the different hosts in regard to the ability to produce perithecia, so it shows also a difference in the ease or difficulty with which the ascus stage may be produced in artificial cultures from the conidial stage. The perithecium of the fungus is superficial, more or less scattered, flask-shaped (Fig. 100), and frequently orange vermilion in color, measuring about $250–350 \times 200–300\,\mu$. The neck may be straight or slightly curved. The ostiolum is closed until a late period with well-differentiated cells, and within the

neck is lined with periphyses. The perithecia are seated upon a slight subiculum.

The wall of the perithecium at maturity is made up of parenchymatous cells more or less polyhedral in form. The asci are cylindrical in the spore-bearing portion and measure often 100–130 × 11–14 μ. Each ascus contains eight spherical ascospores, the latter are brown in color and show at maturity a wrinkled exospore or surface. Paraphyses of somewhat peculiar form are present. These consist of a loose chain of large cells, as shown in Fig. 100, *b*. The development of the perithecium, apparently, has not been studied in detail.

Control. It is believed that it will not be possible to control such wilt diseases by the use of any toxic substances in the soil. Prevention is therefore dependent upon the choice or development of varieties which may be more or less resistant to this fungus, as already suggested. Moreover, it will probably be necessary to look toward the selection of varieties locally resistant, since the relation of such varieties to climatic and soil conditions seems unquestionably to affect resistance to this fungus.

Other wilt diseases. Wilt diseases of various other plants have been studied and some have been referred provisionally to the species of fungus above described, such diseases, for instance, as the stem disease of ginseng, the wilt of the flax, wilt of okra, etc. There are, moreover, other fungous diseases due to species of Fusarium which may or may not be conidial stages of some species of Neocosmospora. Examples of such diseases are to be found in the stem blight and dry rot of potatoes, caused by *Fusarium oxysporum*.

XXXIII. A CANKER OF WOODY PLANTS

Nectria cinnabarina (Tode) Fr.

DURAND, E. J. A Disease of Currant Canes. Cornell Univ. Agl. Exp. Sta. **125**: 23–38. *figs. 1–16.* 1897.

MAYR, H. Ueber den Parasitismus von Nectria cinnabarina. Unters. a. d. forst-bot. Institut zu München **3**: 1–16. *pl. 1.* 1883.

WEHMER, C. Zum Parasitismus von Nectria cinnabarina Fr. Zeitsch. f. Pflanzenkr. **4**: 74–84; Ibid. **5**: 268–276. *pl. 2.* 1894.

Several important fungous diseases are attributed to different species of the genus Nectria. Perhaps the two most destructive

of these Nectrias are *Nectria cinnabarina* (Tode) Fr. and *Nectria ditissima* Tul. Both of these fungi seem to follow other injuries, but either may, after gaining a foothold, spread rapidly from plant to plant and be of the nature of an epidemic.

FIG. 101. NECTRIA ON CURRANT. (Photograph by E. J. Durand)

Distribution. *Nectria cinnabarina* is very commonly distributed throughout temperate regions, at least, and may be found growing upon a great variety of hosts. It has been described as the probable cause of an occasionally destructive disease of currant canes, and in the same state it unquestionably exists as a parasite upon the pear. The horse-chestnut, the china berry, and other trees in various parts of the country frequently show the effects of its injuries. Durand submits evidence to the effect that it is a more or less destructive disease to currants throughout New York,[1] and it has been mentioned as a currant disease in other sections of the country, causing affected parts to dry up and eventually die. In Europe it is also known to cause disease in several hosts, all deciduous trees.

The fungus. The disease seems to infest particularly the cambium and soft bast. It is therefore unlike its relative Neocosmospora, and would seem to be more or less localized, gaining entrance, as previously stated, through wound areas, and probably killing the twig or cane so soon as the latter is girdled. The hyphæ are closely septate, and large stromatic areas are produced upon the epidermis or within the cortex (Fig. 102). These rupture the surface layer and appear as tuberculiform stromata, crowned with minute, short, erect, or flexuous conidiophores which bear simple, ovate conidia. The general appearance of this stroma superficially is that of a pinkish disk. The conidial stage appears usually during the summer, and it is

[1] This fungus is certainly not responsible for the common currant cane disease of eastern New York. The latter, which is typically a wilt, is discussed later.

generally followed later in the season by the development of perithecia, which latter may be differentiated in newly developed stroma, or in the stroma which has borne the Tubercularia stage. A longitudinal section of the perithecia in a related fungus is shown in Fig. 103. The wall of the perithecium consists of an interwoven layer of threads having almost a pseudoparenchymatous appearance. The asci develop from the base and sides, converging toward the apex, each ascus being club-shaped, measuring 60–90 × 8–12 μ, and

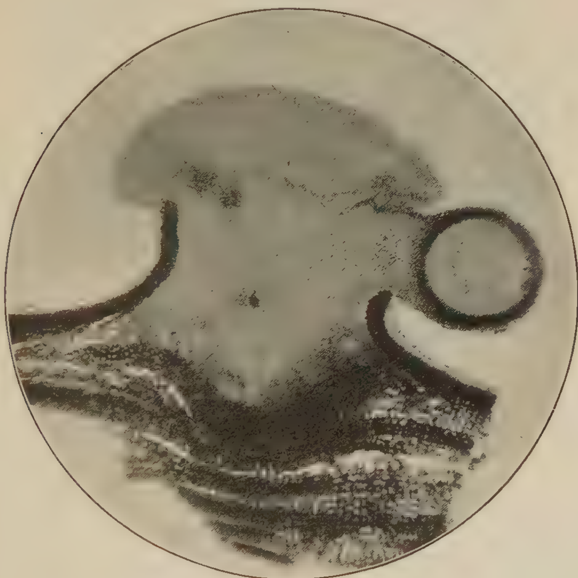


FIG. 102. *NECTRIA CINNABARINA*, SECTION OF SPORODOCHIUM, WITH YOUNG PERITHECIUM. (Photograph by E. J. Durand)

containing eight elliptical spores, which at maturity become two-celled by a partition which may divide the spore into two somewhat unequal parts. The spores are about 14–16 × 5–7 μ.

In artificial culture the mycelium develops rapidly, and usually upon almost any of the nutrient media. Upon canes, stems, or other solid media the tuberculiform stroma is readily produced. Both conidia and ascospores germinate readily. In such cultures conidia are produced irregularly upon small branches of the hyphæ and sometimes abscised more or less directly from large

hyphæ as yeast-like conidial cells. The cushion-like masses also produce conidia in quantity. Mayr described certain macroconidia borne upon small, white stromata preceding the usual cushions on the canes; but Durand was unable to detect such spores.

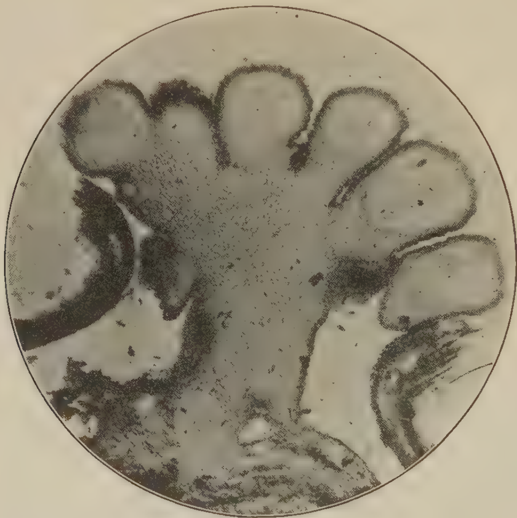


FIG. 103. *PLEONECTRIA BEROLINENSIS:* A CLUSTER OF PERITHECIA
(Photograph by E. J. Durand)

Control. It would seem that the most practical method of control consists in eradicating diseased vines as they appear in the spring, the habit and color of the affected canes giving the necessary clue to their presence.

XXXIV. EUROPEAN APPLE CANKER

Nectria ditissima Tul.

HARTIG, R. Der Krebspilz der Laubholzbäume, Nectria ditissima Tul. Unters. a. d. forstbotan. Institut München **1**: 109–128. *pl. 6.* 1880.

This disease is apparently widespread in Europe upon the apple, and it is not uncommon in the northeastern United States upon the same host. It may also appear on the pear. The fungus seems to gain entrance to the host through wounds, especially hailstone bruises. The mycelium penetrates the bark chiefly, but

to some extent the cambium and the young wood. Much of the injured bark peels off, and as the mycelium is perennial, extending further each season, large cankers may be produced.

Unicellular microconidia generally appear first. These are followed, usually on areas killed the previous season, by pale stromatic cushions of fertile hyphæ producing macroconidia. The latter are twice or more septate, sickle-shaped, and are apparently most important in the distribution of the fungus during the summer. The perithecia develop late in the season, or the following spring, arising in clusters on the stromata.

Control. The fact that this fungus seems to follow other injuries suggests that prevention (where preventive measures are necessary), especially in the case of susceptible plants, may be practiced by simply covering up the wounds with a thorough application of Bordeaux mixture or white paint. For example, immediately after a hail storm or after pruning it might be desirable to use the measures indicated.

XXXV. STEM ROT OF SWEET POTATO AND EGGPLANT

Nectria Ipomœæ Hals.

HALSTED, B. D. The Egg Plant Stem Rot. N. J. Agl. Exp. Sta. Rept. **12**: 281–283. 1891.

This fungus has been described as the cause of the stem rot of the sweet potato (*Ipomœa Batatas*). It is also considered to be responsible for a disease marked by the poor development and unfruitfulness in eggplant in New Jersey. The affected plants manifest the presence of the fungus by a general unhealthfulness, finally yellowing and wilting. An examination of the living plants may disclose a creamy white mycelium near the base of the stem. This mycelium, according to Halsted, bears spores typical of the form genus Fusarium, or the macroconidia of other species of Nectria, that is, curved, hyaline, and pluriseptate. Later the perithecial stage appears in clusters at the base of the stem. Genetic connection between these spore forms has been verified by artificial cultures and by cross inoculation. A comparative study of the spore forms indicates that the disease upon sweet potato and eggplant is produced by the same fungus.

XXXVI. ERGOT

Claviceps purpurea (Fr.) Tul.

De Bary, A. Comp. Morphology and Biology of the Fungi, Mycetozoa and Bacteria, *l. c.*, pp. 35–39, 220–221, 227–228.
Fisch, C. Zur Entwickelungsgesch. einiger Ascomyceten. Bot. Zeitg. **40**: 851–870, 875–897, 899–906. *pls. 10–11.* 1882.
Heald, F. D., and Peters, A. T. Ergot and Ergotism. Neb. Agl. Exp. Sta. Press Bullt. **23**: 1–7. 1906.
Salmon, D. E. Enzootics of Ergotism. U. S. Dept. Agl. Rept. (1884): 212–252. *pls. 5–8.*
Stäger, R. Infectionsversuche mit Gramineen-bewohnenden Claviceps-arten. Bot. zeit. **61**: 111-158. 1903.
Tulasne, L. R. Mémoire sur l'Ergot des Glumacées. Ann. d. Sci. Nat. **20** (Sér. 3): 5–56. *pls. 1–4.* 1853.

Fig. 104. Ergot of Rye

The ergot-producing fungus is of more or less common occurrence as a disease of rye and other grasses. It has never proved a pest of any serious importance so far as its effects upon the host plant are concerned, but it deserves special consideration from the interesting morphological characters of the fungus as well as from the nature and importance of the officinal and toxic extract, commonly known as ergotine, which may be obtained from a certain stage of the fungus. The ergot grains may be accidentally eaten by cattle or horses, and no great amount is required to cause dangerous poisoning or uterine contraction, paralysis, etc. The fungus is widely distributed throughout the United States and Europe, and it has been known botanically more than half a century. It is probably considerably affected by climatic or seasonal conditions, since, as will be seen, it must effect an entrance to the host plant at a particular time, and the spores must therefore be produced in abundance in advance of this period. The principal grasses affected by the species here discussed are *Secale cereale* (rye), *Lolium perenne* (rye grass), *Glyceria nervata*, *Elymus virginicus*, and other grasses of more or less economic importance.

The fungus. The fungus shows an interesting polymorphism, first producing a conidial stage upon the ovule sac, later the sclerotial or true ergot stage in place of the grain, and finally completing its life cycle by developing special sporophores from this sclerotium after a long period of rest has been undergone. The fungus is supposed to gain entrance to the host at the base of the ovule sac or carpel, penetrating the latter and developing through it or over it as a hyphal weft, or primary mycelium, the whole structure maintaining the general shape of the ovule sac, which is gradually replaced by the fungous body. The surface mycelial areas are thrown into folds and numerous short conidiophores arise, bearing small ovate conidia. This is known as the sphacelial stage. Insects are attracted to it by a secretion, and the spores are by this means and by the wind effectively disseminated. Meanwhile, a dense growth of the fungus makes its appearance at the base of the affected part and gradually enlarges as a firm, compact body, or sclerotium. It gradually replaces the area occupied by the sphacelial stage, becomes purplish in color, and in time projects beyond the usual dimensions of the normal ovule sac, pushing forward upon its tip the remnant of the sphacelial stage and any portions of style and stigma which may remain. The sphacelial stage and the remnants of the ovule sac are finally brushed away or fall off and the mature sclerotium is in the form of a very hard, purplish or brown, slightly curved or horn-shaped body, which may attain a length of from one half to one and one-half inches (Fig. 105). The development of this sclerotial stage requires about the same length of time as is needed for the development of the grain in the normal ovule sacs. It is therefore mature at the time that the grain is mature.

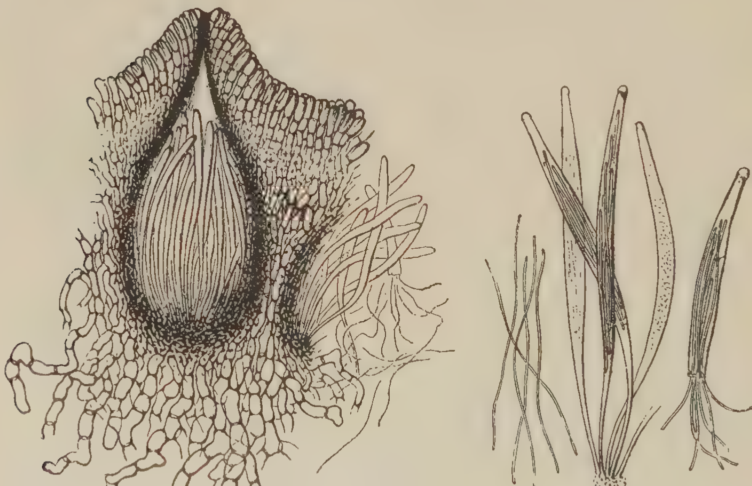
FIG. 105. *CLAVICEPS PURPUREA:* SCLEROTIUM WITH STROMATA

The sclerotium readily falls from its place of production and must then undergo a long period of rest before it is in condition to be brought to germination. In this particular species germination in nature apparently results early the following spring.

Germination really consists in absorption of water, increase in size of the sclerotial mass, and the pushing into growth, sometimes from many different points on the sclerotium, of compact masses of hyphæ, which develop into sporophores. These sporophores may be from one fourth to one inch in height, and they bear at the summit head-shaped stromata within which the perithecia are differentiated. A cross section of the head-shaped stroma is shown in Fig. 106, *a*.

a

The sporophore consists of a stalk from one half to one inch in length, terminated by a capitate enlargement about twice the diameter of the stalk portion. In the stromatic tissue of



b *c*

FIG. 106. *CLAVICEPS PURPUREA:* SECTION OF STROMA AND ENLARGED PERITHECIUM; ALSO ASCI AND SPORES. (After Tulasne)

the head numerous perithecia are formed near the periphery. So far as is known, a perithecium is developed in two successive stages: (1) By the repeated division of a few differentiated cells below the surface there results an ellipsoidal pre-ascal tissue. (2) In the proximal or basal portion of this cellular body an hymenium

originates, and the asci to which it gives rise obtain room for complete development either by forcing the separation of the cells in the center of the cellular body or by dissolving some of these. The mature perithecium consists of a flask-shaped structure, the mouth of which projects, along with the tissues which inclose it, slightly beyond the general level (Fig. 106, *b*). Within the neck of this perithecium are to be found many periphyses. The mature asci are long-clavate. Each ascus contains eight filiform spores, averaging 60–70 μ in length, which issue from the tip of the ascus and readily germinate in water (Fig. 106, *c*).

FIG. 107. USTILAGINOIDEA ON RICE. (Photograph by H. R. Fulton)

Control. Proper precautions in the selection of the grain seed, together with thorough preparation of the land, obviate any danger in the case of rye. When detected in the harvested product, the sclerotia must be shaken out or the product discarded. When ergot appears in abundance on grasses in the pasture, either the animals must be taken off until the ergot falls, or, where possible, the grass may be mowed with a machine the blade of which may be set high. In the latter case subsequent raking may be unnecessary. In the central West, ergot is not uncommon on the chief pasture crop, blue grass (*Poa pratensis*). This may not be ergot of rye, for besides that species, two ergot-producing fungi have been reported on Poa, *Claviceps microcephala* (Wallr.) Tul. and *Claviceps setulosa* (Quel.) Sacc.[1]

[1] A disease of rice known as green smut is well developed in the rice-growing regions of Japan and Louisiana. The effect of the fungus is conspicuous (Fig. 107), although only a few grains in a head are affected. The disease has every appearance externally of being a smut. Brefeld (Unters. a. d. Gesammtg. d. Myk. **12** : 194) and others have studied this form. Brefeld has studied also more particularly a related species on *Setaria crus-ardeæ*. In both cases the smut-like body is a typical sclerotium surrounded by looser hyphæ and the dark walled spores. Germination studies of the spores seem to indicate that they are conidia, and it has been suggested that the fungus may prove to be an ascomycetous form, possibly one of the Hypocreales. The species on rice bears the name *Ustilaginoidea Oryzæ* (Cke.) Tak.

XXXVII. DOTHIDIACEÆ

This family includes several hundred species, very few of which, however, are of great importance as disease-producing parasites. It is characterized by asci arising, apparently, for the most part, directly from the stromatic tissue, or at least by a very indistinct perithecium, or perithecial wall. They differ from the Hypocreaceæ especially in the color of the stroma, which is dark to black. The most important species, *Plowrightia morbosa*, black knot of the plum, is discussed at length, but the genus Phyllachora is important from the number of its species and the variety of its hosts.

XXXVIII. BLACK KNOT OF PLUMS AND CHERRIES

Plowrightia morbosa (Schw.) Sacc.

BEACH, S. A. Black Knot of Plum and Cherry. N. Y. Agl. Exp. Sta. Bullt. **40**: 25–34. 1892.
FARLOW, W. G. The Black Knot. Bussey Institution, Bullt. (1876): 440–453. *pls. 4–6.*
HALSTED, B. D. Destroy the Black Knot of Plum and Cherry Trees. N. J. Agl. Exp. Sta. Bullt. **78**: 1–14. 1891.
HUMPHREY, J. E. The Black Knot of the Plum. Mass. Agl. Exp. Sta. Rept. **8**: 200–210. *pl. 1.* 1890.
LODEMAN, E. G. Black Knot. Cornell Univ. Agl. Exp. Sta. Bullt. **81**: 637–657. 1894.

This is one of the most common and most striking fungous diseases of fruit trees in the United States. It has been known and described in orchard literature since the early part of the nineteenth century, and the causal fungus was described by Schweinitz in 1822. For a long time, however, the knot was commonly supposed to be caused primarily by insects. A considerable literature upon this disease accumulated, but it was not until 1876 that a thoroughly competent account of the fungus and its relation to the knot was presented. This latter account has remained the chief basis of opinions concerning this fungus.

Geographical. The black knot was apparently at one time confined largely to the Atlantic seaboard, and was particularly abundant only in New England and perhaps New York. It is now known to extend across the northern United States to the Pacific Coast, although very large portions of the Southwest and large areas of

the central West are practically free from this disease. In spite of the interchange of plants between Europe and America, the black knot has not yet been reported from either England or from the continent, and so far as can be ascertained, it is not known to occur in other countries.

Host plants. Very few of the native species of plum or cherry are free from this fungus. Among those which suffer particularly from the disease may be mentioned the Chickasaw plum (*Prunus angustifolia*), the yellow plum (*Prunus americana*), the wild black and red cherries (*Prunus serotina* and *Prunus pennsylvanica*), chokecherry (*Prunus virginiana*), the bird cherry (*Prunus avium*), and the morello varieties (*Prunus Cerasus*). It is said to occur upon other species, but definite records are not at hand. On account of the fact that this fungus attacks wild plums as well as cultivated, it is a constant source of danger to plum growing wherever the native plums abound in neglected places. In certain seasons the knot will be found in abundance upon some species only, while it will almost entirely omit other hosts. This has prompted the opinion that there may be several species or forms of the fungus affecting the different hosts. This may be true, but it would appear to be almost as well explained by admitting the very evident fact that certain hosts are in general more susceptible and by assuming that during some seasons particular species may be rendered peculiarly susceptible.

Symptoms. The black knot is a most unsightly disease, consisting of wart-like hypertrophies or excrescences which may cover a considerable area on the twigs and limbs. It is confined entirely to the woody parts. The term *black knot* applied to this disease is a very fortunate one, since the deformities take the form of elongated blackened knots, usually extending a distance of from one or two to four or five inches upon the affected branches. For the most part the injury is confined to one side of the branch, or at least it does not generally form a complete ring, which would effectually cut off the nutriment from the tip portion. The first appearance of the knot is usually noted in the spring, although it has also been observed to make its appearance in the fall (Humphrey). At first it consists of a slight swelling of the branch, originating upon any portion whatever, but generally on

that portion of a limb bearing a side branch. It may arise independently, or near an old knot. As the swelling increases in size the bark is broken and the stroma of the fungus then becomes

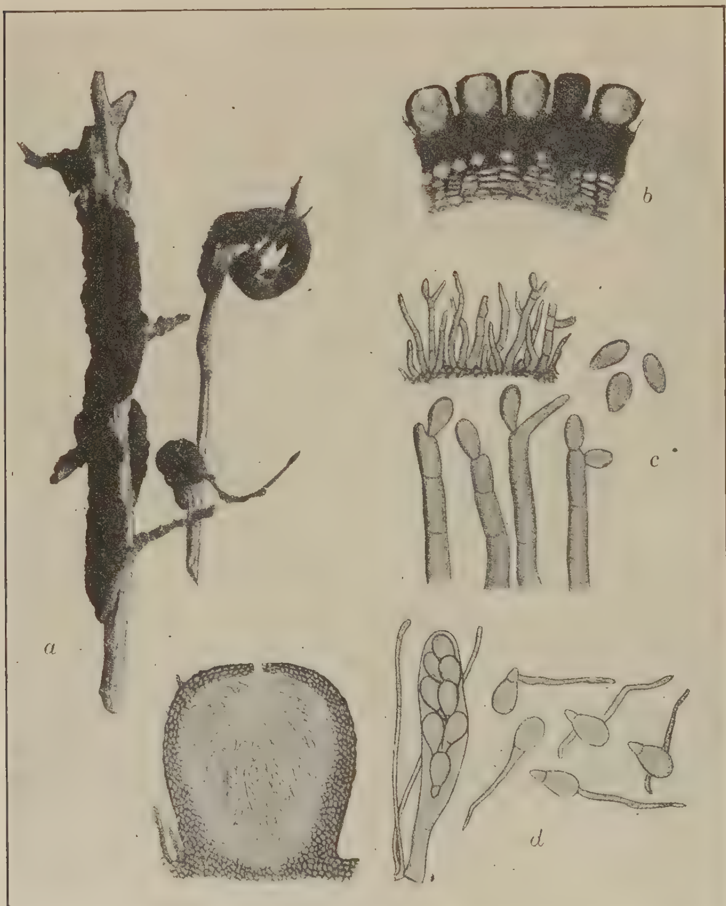


FIG. 108. *PLOWRIGHTIA MORBOSA*, BLACK KNOT OF PLUM. (After Longyear)

evident. By midsummer the knot will have attained full size, and from that time until the winter, or as long as the remnants of the knot may persist, it will be deep black and carbonaceous in texture (Fig. 108, *a*). In the case of small twigs which are affected, bending may be caused, so that a right angle will be made from

the knotted side. While the smaller twigs are usually affected, the knot may also be found upon branches nearly two inches in diameter.

The fungus. The mycelium of the fungus is found during the early stages occupying most of the cambium and the bast areas, as well as extending throughout the cortex. If the whole cambium ring becomes affected the girdling causes the death of the limb beyond. In general, however, the growth of the twig continues, since the fungus is confined to one portion of the cambium, growing from this layer towards the periphery. The knot itself is made up of a mass of tissue, comprising, on the one hand, dense areas of the fungus and, on the other, various cells or tissue elements of the host. Bast fibers, parenchyma cells, and even vessels may be found in this heterogeneous mass in which all of the associations of cells normally present have disappeared. This abnormal condition is apparently brought about by the breaking up of the cambium and a resulting development of all the various cell forms to which it may give rise in the diverse isolated areas. The distribution of the fungous hyphæ and the minute anatomy of the knot varies upon different hosts.

During the development of the knot in the spring, small, greenish areas may be noticed upon the surface, and later the mycelium breaks through the bark from all directions and forms upon the surface a very dense layer of closely adherent or pseudoparenchymatous cells. This stromatic fungous layer gives rise to conidiophores, which are flexuous and septate (Fig. 108, *c*). Each conidiophore produces a spore at the tip, and by further growth scars, geniculations, or short branches may result. The conidiophores are produced in such quantity that the surface has a velvety appearance; they measure from $40–60 \times 4–5\ \mu$. The conidia are simple, and light brown in color. The period of conidial production usually extends from late spring until midsummer. Gradually, as the season advances, the velvety surface disappears, disclosing a deep black stroma which has been gradually differentiated. From an early period there can be observed with a hand lens certain papillæ which locate the forming perithecia in this stromatic area. The later conidiophores are therefore still evident on the surface when developing perithecia are easily

demonstrated through sections. The perithecium contains at maturity the ascospores, or perfect stage, of this fungus. Owing to the dense structure of the knot, it is almost impossible to follow closely the stages of development in the hymenial tissue and in the formation of the asci. The asci, at any rate, develop during the winter, and the spores are ripe during midwinter or later, depending upon the region. Each mature ascus is about 120μ in length, and contains eight spores, the spores being two-celled by a cross wall which separates unequal portions. They may be variously arranged in the ascus but are often obliquely uniseriate, each being $16–20 \times 8–10\mu$. Paraphyses are always present. These are filiform, nonseptate structures with a slightly enlarged tip. Other spore stages, a stylosporic and a pycnidial stage, have been found associated with the two already described, but they are not of common occurrence, and may not represent fixed and common stages in the life history of this species.

The conidia and the ascospores germinate in plum juice or upon various nutrient media, and pure cultures may be readily made upon solid media. The spores also germinate in water. Humphrey succeeded in developing a pycnidial form upon nutrient gelatin which differed from any stage of the fungus found on its natural hosts.

In spite of the good work which has been done upon the development of this fungus, there is opportunity for much more careful morphological study. It would be necessary to study the plant upon different hosts and upon various culture media in pure cultures in order to determine the ultimate relationships of the different spore forms which have thus far been described.

Control. It is evident that since the conidial stage is produced abundantly during late spring and early summer, pruning out of the developing knots just prior to the season mentioned would largely control the spread of this fungus by the conidial stage. A similar careful pruning should be given prior to the development of the ascospores, if any knots have been overlooked. It would be well, however, to make several prunings during the year if this method of eradication alone is practiced. The suppression of black knot has been a subject of legislation in many states, and in those in which it is fairly well under control, pruning is usually

sufficient to prevent the spread from occasional outbreaks. Since, however, wild plums and cherries everywhere may be affected, eradication is difficult. In many regions the fungus is so common and so persistent that it is necessary to take additional precautions. Spraying with Bordeaux mixture has been advised, and where spraying is given, one application should be made during the late winter and one when the buds begin to swell. This latter should be followed by two or three subsequent applications as may seem necessary. It has been thoroughly demonstrated, however, that the disease is controllable, and when coöperation is given, eradication in large areas is perhaps possible.

XXXIX. SPHÆRIALES

The sphæriaceous Ascomycetes constitute an order (sometimes considered a suborder) containing more species than perhaps any other equivalent natural group of the fungi. The great majority are saprophytic in habit, occurring upon decaying twigs, leaves, and, in fact, upon practically all kinds of vegetable matter, or upon the soil. There are some notable parasitic species, but these are relatively inconsiderable as compared with the great number of saprophytes.

The mycelium may be light or dark colored, usually the latter, and the perithecia show very diverse characters with respect to texture and form of the ostiolum, as also with relation to the substratum and stroma. They may be free, slightly connected by a scant subiculum, or more or less imbedded in a stromatic tissue of variable texture. The perithecia vary from membranous to carbonaceous, delicate, tough, or brittle, and the ostiolum may be merely a circular aperture, a slight papillate opening, or a long beak. What has been said of conidial stages under the Ascomycetes in general applies in particular to this group, these stages being manifold, so far as the method of conidiospore production is concerned.

This order is commonly subdivided into eighteen families, which differ from one another, however, in characters so slight that a brief key of those which are here to be considered may be sufficiently descriptive.

A. No stroma present; perithecia for the most part completely immersed in the substratum, or finally becoming more or less free by the rupture of the inclosing matrix (epidermis in the parasitic forms).

1. Perithecia for the most part without distinct beak, tough but not carbonaceous.

a. Asci arising in groups from the perithecial wall without intervening paraphyses . *Mycosphærellaceæ*
(Represented by *Guignardia* and *Mycosphærella*.)

b. Asci arising from the base of the perithecium and not in groups. Paraphyses present. *Pleosporaceæ*
(Represented by *Venturia*.)

2. Perithecia carbonaceous or tough leathery, as a rule with a distinct beak. Asci thickened at the apex, commonly breaking open by a pore . . . . . . *Gnomoniaceæ*
(Represented by the genera *Glomerella* and *Gnomonia*.)

B. No stroma present; perithecia free upon the substratum, or surrounded at the base by a dense mycelial mat . . . . *Sphæriaceæ*
(Represented by *Rosellinia*.)

C. Stroma present, consisting of intermixed and modified fungous and host elements; perithecia imbedded; pycnidia present . . . *Valsaceæ*
(Represented by *Diaporthe*.)

D. Stroma present, consisting of fungous hyphæ only; perithecia immersed . . . . *Xylariaceæ*
(Represented by *Nummularia*.)

XL. BLACK ROT OF GRAPES

Guignardia Bidwellii (Ell.) Viala & Ravaz

Edson, A. W. The Black Rot of the Grape in North Carolina and Its Treatment. N. C. Agl. Exp. Sta. Bullt. **185**: 131–150. 1903.

Jaczewski, A. V. Über die Pilze, welche die Krankheit der Weinreben "Black Rot" verursachen. Zeitsch. f. Pflanzenkr. **10**: 257–267. *figs. 1–8.* 1900.

Reddick, D. The Black-Rot of the Grape and Its Control. Cornell Univ. Agl. Exp. Sta. Bullt. **253**: 367–388. *figs. 177–187.* 1908.

Report on Experiments made in 1888 in the Treatment of the Downy Mildew and Black Rot of the Grape Vine. U. S. Dept. Agl. Bot. Div. Bullt. **10**: 1–61. 1889.

Scribner, F. L. The Fungous Diseases of the Grape Vine. Bot. Div. U. S. Dept. Agl. Bullt. **2**: 28–34. *Ill.* 1886.

Scribner, F. L. Fungous Diseases of the Grape and Other Plants and their Treatment. 1890.

Viala, P. Les maladies de la vigne. 595 pp. *19 pls. 290 figs.* (Black Rot: 156–203. *pl. 4. figs. 48–54.*) 1893. Montpellier et Paris.

Viala, P., et Ferrouillat, P. Manuel pratique pour le traitement des maladies de la vigne. 1888.

Distribution. The most serious menace to grape growing in most sections of the United States is the well-known black rot, a fungus of American origin, the effects of which have been known for considerably more than half a century.

The black rot is now very generally distributed throughout the grape-growing sections of the United States and is reckoned with as a constant foe wherever susceptible varieties are grown. It is supposed to have been introduced into France somewhat more than twenty years ago, and it is now common in other sections of Europe, and throughout the Mediterranean region. Its ravages are more serious under the conditions which commonly

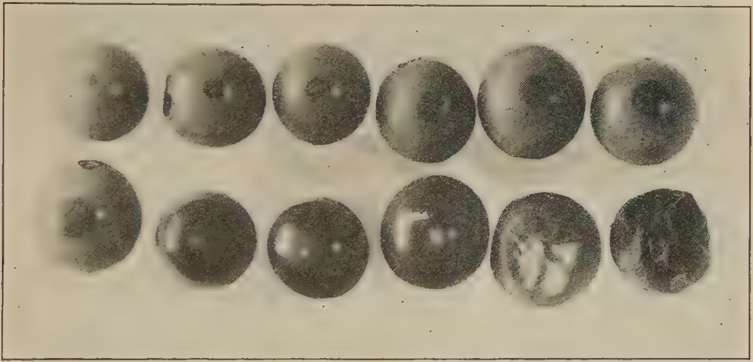


FIG. 109. BLACK ROT OF GRAPE, SHOWING PROGRESS OF THE DISEASE
(Photograph by Donald Reddick)

encourage the growth of parasitic fungi, that is, moist, warm days, or the muggy weather of midsummer, being particularly favorable for its rapid development and spread.

Symptoms. The black rot fungus occurs upon the berries and leaves (Figs. 110, 111), also upon fruit pedicels, and sometimes upon young canes. The berries are most severely affected, although the disease may first be seen upon the leaves. Upon the latter it appears as sharply defined, nearly circular, brown spots. Sooner or later small pycnidia may be found at the centers of these spots. The berries are not ordinarily attacked until about two thirds grown. The first sign of injury is the appearance of a purplish or livid brown spot, which normally spreads over the whole surface of the berry. The affected fruit gradually becomes

darker in color, and pycnidia, appearing as black papillæ, may be produced over the entire surface. At this stage the effects of the fungus are therefore unmistakable. Later the fruit shrivels in a characteristic manner, but does not, as a rule, fall or shell. The berries on bunches thus affected may hang on the vines throughout the season. The pycnidia may also be easily observed with the unaided eye upon the dried berries.

Susceptibility of varieties. It seems to be the general experience that practically all of the more commonly cultivated varieties of grapes, particularly, however, the dark colored varieties, including Concord, Hartford, Roger's Hybrids, etc., are susceptible. In some districts certain light colored varieties are more resistant and the Scuppernong is practically free from attack. In this case, however, as in many others already mentioned, there is a great difference in the resistance of varieties according to their environmental conditions. For all commercial purposes grape growing would be impossible in most localities, on account of the great losses entailed, if the disease were not practically controllable by spraying operations.

FIG. 110. GRAPES AFFECTED BY BLACK ROT
(Photograph by F. C. Stewart)

The fungus. The mycelium of this fungus is found in the outer portions of affected berries, but mycelium is never abundant. Under favorable weather conditions only about one week may be required from the time of infection to the development of the pycnidia, — ordinarily 8–12 days are necessary. The pycnidia have long been known under the name *Phoma uvicola* B. & C. Upon the leaves the pycnidial stage has passed under the name *Phyllosticta Labruscæ*. The pycnidium develops from a stromatic

mass of mycelium which arises beneath the epidermis. It is broadly elliptical, with a rather thick wall and no indication of a beak (Fig. 112, *a*). The conidiophores are short and simple, bearing spores — ovate or elliptical — measuring ordinarily $8–10 \times 7–8\,\mu$. In moist weather the spores are pushed out in vermiform

Fig. 111. Phyllosticta Stage of the Black Rot Fungus
(Photograph by H. H. Whetzel)

masses and upon dissemination they are capable of immediate germination. Accompanying these pycnidia (the spores of which are frequently known as stylospores) there may be found somewhat smaller, more nearly spherical pycnidia (commonly but unfortunately known as spermagonia). The latter contain relatively long filiform conidiophores converging towards the center, and

upon these are borne minute, cylindrical, or slightly curved conidia. It is, however, doubtful if this last mentioned pycnidial form is either common or of much consequence in the rapid distribution of the fungus.

The ascigerous stage was first found and named in 1880, and since that time the name has been more frequently changed than has the fungus been accurately studied. It is stated that the asci were first found upon berries which had hung upon the vines during the winter and had subsequently been dropped into water for a few days. Since that time the perfect stage (Fig. 112, *b*) has been frequently detected on affected berries which have lain under favorable conditions during the spring months, as when covered by leaves and grass. It would seem, however, that very few observations have been systematically made to determine the time of development of the ascospores. The asci may apparently develop in perithecia which have previously served as pycnidia, or resting stromatic masses may give rise to the perithecia directly. The asci are broadly clavate, sometimes slightly curved, and they contain eight nonseptate, hyaline spores, the latter measuring 12–17 × 4.5–5 μ. They are generally ovate.

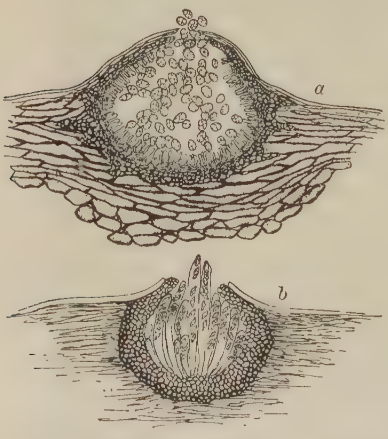


FIG. 112. *Guignardia Bidwellii*: SECTIONS OF PHOMA AND ASCIGEROUS STAGES

Control. The most efficient remedy for the black rot is Bordeaux mixture. After cleaning the vineyard as well as possible of the pruned and diseased litter, the old berries being covered by early plowing, Bordeaux should be thoroughly applied, covering vines, posts, and trellis just as the buds are swelling in the early spring. A second application is made as the buds unfold, and subsequently the vines should be sprayed about every two weeks, until five or six applications have been made. The nature of the season, however, will determine how late it will be

necessary to continue such operations. To one familiar with the life history of the fungus it is evident that the time for spraying will be governed by the condition in which the fungus is found. When no spores are being produced spraying may be unnecessary; when spores are being produced in quantity weekly sprayings may be demanded. Moreover, when it is necessary to spray during the late season, ammoniacal copper carbonate may be substituted for the Bordeaux, in order to avoid the unattractive discoloration of the fruit.

XLI. CRANBERRY SCALD

Guignardia Vaccinii Shear

SHEAR, C. L. Cranberry Diseases. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **110**: 1–64. *pls. 1, 2.* 1907.

Distribution and effects. Under the name of scald a number of fungi affect the cranberry, but the most important diseases of this plant are produced by the fungus above mentioned. It has been estimated that the annual loss from cranberry scald is about $200,000, and that this fungus is responsible for the greater part of this amount. The disease is more common toward the southern limit of cranberry culture, especially from New Jersey southward, whereas further to the north, as in Massachusetts, it is far less destructive.

The fungus may attack very young fruit, and even flowers, which promptly shrivel and die. The latter effect is commonly known as "blast." Upon such parts the pycnidial stage of the fungus is commonly found. The term *scald* is applied particularly to the effect upon the berry, which begins, according to Shear, as a small watery spot upon the surface of young fruit. This spot may remain small under certain conditions, and again it spreads quickly, often concentrically, rendering the whole berry soft, and sometimes marked by rings. This, however, is not a definite character. There is little superficial evidence of the presence of the fungus, unless the berries are attacked before they are half grown, when they may promptly shrivel and develop the pycnidia of the fungus. The fungus also affects the leaves, and when found upon these parts, brown spots, irregular in outline,

are produced within which areas the pycnidia may be found. Cuttings may also be affected.

The fungus. The pycnidial stage is a characteristic Phoma or Phyllosticta, 100 to 120 μ in diameter, as shown in Fig. 113. These are distributed over the affected surfaces, and produce abundant conidia, which are hyaline, obovoidal, frequently truncated at the apex, measuring $10.5–13.5 \times 5–6 \mu$. The conidia are appendaged, and they are expelled from the perithecium much as in the black rot of the grape. The ascogenous form is less commonly found. In this the perithecia are much as those already described, except that the wall is denser and they bear only asci. The latter are more or less clavate, with a total length of from

FIG. 113. *GUIGNARDIA VACCINII* ON CRANBERRY: PYCNIDIAL AND ASCIGEROUS STAGES. (After Shear)

60 to 80 μ. The spores are hyaline when young, and tinted when old. They are described as elliptical or subrhomboidal in form, with granular contents (Fig. 113, *b*).

This fungus has been carefully cultivated, cultures being made from both stages and from hyphæ, as well as from the tissue of the host beneath the scalded area upon the berries. It is reported to grow well upon acid and neutral media, and especially vigorous upon corn meal in various combinations. The pycnidial form has been produced in culture; yet in many cultures the conidia are not produced in the perithecia, but the latter remains as a more or less sclerotial organ. The ascogenous form, however, has been secured in cultures from both berries and leaves. After a few generations in culture tubes, the fungus appeared to lose considerably in vitality, and frequently developed no spore forms

after one or two generations. In general, the conditions under which growth takes place do not seem to affect to any great extent production of fruiting stages. It is believed also that after the fungus has penetrated the host it may remain under favorable conditions inactive for some time, and that therefore the period of incubation may be long or short, depending upon conditions. The ascogenous form has not been found abundantly in nature, and may not be very important in the distribution of the fungus.

Control. Prevention should concern itself particularly with sanitation, including the renovation of the cranberry bog, proper regulation of the water supply, and the development of disease-resistant strains. Spraying with Bordeaux mixture has also proved of value. In spraying, however, the addition of substances rendering the mixture more adhesive is necessary.

XLII. LEAF SPOT OF STRAWBERRY

Mycosphærella Fragariæ (Tul.) Lindau

Dudley, W. R. On the Strawberry Leaf-Spot. Cornell Agl. Exp. Sta. Bullt. **14**: 171–184. 1889.

Scribner, F. L. Strawberry Leaf Blight. U. S. Dept. Agl. Rept. (1887): 334–341. *pl. 1.*

One of the diseases of the strawberry most frequently met with is that commonly known as the strawberry leaf spot. The disease makes its appearance in the form of small, discolored spots, appearing upon the leaves most abundantly about the time of flowering (Fig. 114). At first these spots are of a reddish or purplish tint, but as they increase in size the center becomes pale and may be quite white when the death of the tissues has ensued. This white central area is ordinarily bordered by a zone of red and purple in different shades. These spots are irregularly distributed over the leaves, and when numerous they may coalesce. All of the cultivated varieties of strawberries may be affected, although there is considerable difference in the degree of susceptibility. Among some of the berries most susceptible in the northeastern United States may be mentioned the Hunn and the Beeder Wood. Susceptibility of a variety varies, however, when cultivated under different conditions. Marshall and Brandywine have often proved very resistant.

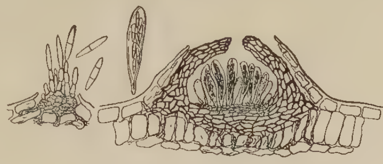
The fungus. The life history of the fungus has been considerably studied, and it is probable that some spore stages which have been described are not at any rate common stages in the life cycle. In general, two spore-producing stages may be found, the conidial and the ascigerous stages. The conidial stage has been described as *Ramularia Tulasnei*. This appears in early summer, as a rule, or so soon as the pale centers of the spots have been developed. Small, tuberculate stromatic masses are produced upon the mycelium beneath the epidermis, and from these arise a small group of simple hyphæ, which rupture the

FIG. 114. LEAF SPOT OF STRAWBERRY

epidermis and produce conidia which may become one or several times septate. The conidia, according to Dudley, measure 20–40 × 3–5 μ (Fig. 115, *a*).

The ascigerous stage is not so commonly found and is in no case developed until late summer. A membranous perithecium, characteristic of this family, is then produced within the leaf, although at maturity a considerable part of the perithecium may be exposed. Relatively few asci are developed, the asci containing invariably eight hyaline, uniseptate spores with acute tips (Fig. 115). It would appear that the spores are not ordinarily mature until late winter, or at least not ejected until that time. Moreover,

hibernation is supposed to be effected in some cases by means of the tuberculate stromata, which retain their vitality and serve as minute sclerotia, germinating the following spring. The asci average 40μ long, and the spores measure about $15 \times 3–4\mu$.



a b

FIG. 115. *Mycosphærella Fragariæ*, Conidial and Ascigerous Stages

Control. Healthy plants only should be set, and all spotted leaves should be pinched off. A thorough spraying with Bordeaux mixture may be given before the flowers are open, when necessary. If the disease is serious or disastrous late in the season, its reappearance the next year may be delayed and to some extent averted by mowing off the leaves and burning over the bed.

XLIII. LEAF-SPLITTING BLIGHT OF SUGAR CANE

Mycosphærella stratiformans Cobb

COBB, N. A. Fungous Maladies of the Sugar Cane. III. Leaf-Splitting Blight. Hawaiian Sugar Planters Exp. Sta. Bullt. **5**: 93–106. 1906.

This is the name provisionally applied to a fungus which causes a peculiar leaf-splitting of sugar cane in portions of the Hawaiian Islands. The leaves are split, and in severe cases reduced to shreds. The ascogenous stage alone has been reported. The perithecia are produced abundantly. Diseased stalks should not be planted, and all leaf trash from an affected field should be destroyed. What appear to be related species of fungi have been described as injurious to cane in Java and in La Plata, Argentina.

Mycosphærella Cerasella Aderh.[1] is considered to be the ascogenous form of *Cercospora Cerasella* Sacc., well known upon the leaves of cherry, sometimes producing a shot hole effect similar to that which may follow any leaf spot fungus parasitic upon species of Prunus.

[1] Aderhold, R. Mycosphærella cerasella n. spec., die Perithecienform von Cercospora cerasella Sacc., und ihre Entwicklung. Ber. d. deut. bot. Ges. **18**: 246–249. 1900.

XLIV. APPLE SCAB AND PEAR SCAB

Venturia Pomi (Fr.) Wint. and *Venturia Pyrina* Aderh.

ADERHOLD, RUD. Die Fusicladien unserer Obstbäume. Landwsch. Jahrb. **25**: 875–914. *pls. 29–31.* 1896; Ibid. **29**: 541–587. *pls. 9–12.* 1900.

BEACH, S. A. Experiments in Preventing Pear Scab in 1893. N. Y. Agl. Exp. Sta. Bullt. **67**: 183–204.

CLINTON, G. P. Apple Scab. Ill. Agl. Exp. Sta. Bullt. **67**: 109–156. 1901. (Good bibliography.)

DUGGAR, B. M. Some Important Pear Diseases. Cornell Agl. Exp. Sta. Bullt. **145**: 616–622. *figs. 168–170.* 1898.

LAWRENCE, W. H. The Apple Scab in Western Washington. Washington Agl. Exp. Sta. Bullt. **64**: 1–24. *pls. 1, 2.* 1904.

SMITH, RALPH E. Pear Scab. Calif. Agl. Exp. Sta. Bullt. **163**: 1–18. *figs. 1–9.* 1905.

Two important fungous diseases popularly known as apple and pear scab have received at the hands of both mycologists and horticulturists considerable attention within the past thirty years. The fungi causing these diseases are very closely related, although quite generally referred to two distinct species. The conidial form of each of these fungi was first found parasitic upon its respective host; hence these fungi have long been known by the names of these conidial forms, *Fusicladium dendriticum* and *Fusicladium Pyrinum*. More recently an ascomycetous fungus, *Venturia Pomi*, has been found to constitute the perfect stage of the apple scab organism, and a related perithecial form, *Venturia Pyrina*, has been connected with the pear scab fungus. The perithecial stages develop saprophytically, a phenomenon characteristic of many Ascomycetes.

FIG. 116. A SEVERE ATTACK OF PEAR SCAB ON FLEMISH BEAUTY

Distribution and climatic relations. In the United States both the scab of the apple and of the pear are widely distributed.

Moreover, the data at hand seem to indicate that they occur in all countries in which the host plants are commercially grown. These fungi are apparently of economic importance in all sections of the United States where the weather may be cool and damp during portions of the spring and summer. In the northern portion of the United States it has received particular attention at the agricultural experiment stations of Vermont, New York, Illinois, also California, thus indicating a very general distribution. It is, however, believed to be equally distributed in the Southeast, but in that section it has received less attention, perhaps on account of the fact that the commercial output of these fruits has not been a factor of such importance. In the past few

FIG. 117. THE EFFECTS OF APPLE SCAB DURING A MOIST SEASON

years these diseases have become a menace on the Pacific Slope. All investigators, however, are agreed that cool, moist weather either in spring or summer encourages the rapid spread of the fungus, while hot winds quickly suppress it.

Losses. It is not easy to estimate the average losses from these fungi, and this is particularly true on account of the fact that the scab fungi are more or less superficial in their effects. In severe cases the fruit is wholly unmarketable, but in too many cases scabby fruit is regularly put upon the market and the reduced prices which it brings are not estimated. During seasons favorable for the fungus, probably one year in two, the losses in many sections of the country amount to a reduction in price or total destruction of from 25 to 50 per cent of the entire crop.

The relation of host and fungus. These fungi commonly affect fruit and leaves, but they may also be found upon leaf stalks, flowers, and twigs. Upon the leaves (Fig. 118) in each case the spots are more abundant, as a rule, upon the lower surface. Where the fungus is made evident by an olivaceous, velvety, superficial growth, or when the disease is very abundant, both surfaces of the leaf may be covered and considerable curling

FIG. 118. APPLE SCAB ON LEAVES: DIFFERENT TYPES OF INFECTION

may result. Upon the fruit there are at first small, circular, olivaceous spots, especially upon the pear, but as a rule the appearance changes as the fungus spreads, the epidermis is killed, and the familiar scabby spots are produced. At times practically the whole fruit may show indications of the fungous growth, and a general puckering of the tissues may result in an abnormal form of the fruit. Some varieties of pear may develop cracks or fissures extending halfway to the core. Fig. 116 shows a severe attack of scab on Flemish Beauty.

There are probably no varieties of the pear or apple which are entirely free from scab. Nevertheless, there is a great difference in susceptibility. In New York, Flemish Beauty, Summer Doyenne, Duchess, Clairgeau, Sheldon, Seckel, Anjou, and Lawrence have been reported as more generally affected than Le Conte, Kieffer, and Bartlett. In California the later varieties like Winter Nellis and Easter Beurre are said to be more susceptible than the Bartlett, which, however, is only resistant to an intermediate degree. The susceptibility of different varieties of apple to the apple scab seems to vary considerably according

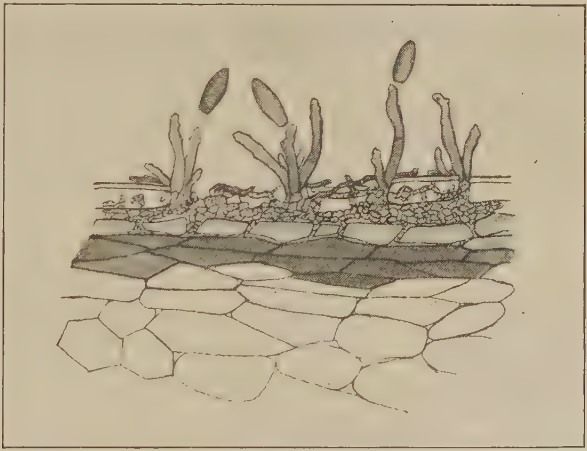


FIG. 119. CONIDIAL STAGE: FUSICLADIUM OF THE PEAR SCAB FUNGUS

to the region in which grown, yet nearly all of the standard varieties may be affected during seasons favorable to the fungus.

The fungus. The spores of the Fusicladium stage germinate readily in water and develop a short germ tube, or sometimes two germ tubes. The germ tube sometimes forms a dark spore-like structure, if the conditions are not favorable for further rapid growth. This structure is scarcely in the nature of an appressorium, and may be considered a resting stage, which will grow out into mycelium under favorable conditions. It is believed that the mycelium of these two species of fungi develops for a short time superficially, then penetrates the epidermis in some way. At any rate, the mycelium is found at a very early stage beneath

the epidermis, and between the epidermis and cuticle. In these situations it spreads slowly. According to some writers the principal development at first is immediately beneath the cuticle. That is particularly true, according to reported observations, on the leaves. On the fruit, however, both the cuticle and the epidermis are soon broken and disappear as the spot becomes scabby in appearance. Upon the pear I have quite generally found the mycelium to be subepidermal at the edge of the scabby spots. It may form a layer several times as thick as the diameter of the hyphæ, and as the epidermis wears off, this mycelial layer is exposed, and beneath this the cells of the host may become corky, as shown in Fig. 119. The mycelium is olivaceous or sometimes reddish-brown in color, closely septate, sinuous and irregular in branching.

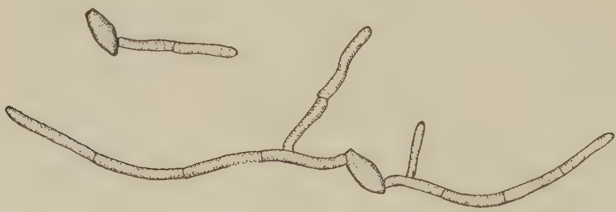


FIG. 120. GERMINATING SPORES OF FUSICLADIUM

The olivaceous growth on the surfaces of the fruits, leaves, and twigs is, however, made up very largely of the short, erect conidiophores. These conidiophores arise from the subcuticular or subepidermal mycelium, break the cuticle if the latter is still intact, and a spore is soon developed at the tip of each. A spore may be borne when the conidiophore has attained a length of four or five times its diameter. However, when this spore is abscised, the conidiophore grows further, leaving a slight knee or other evidence indicating the point where the previous spore was borne. In this manner many successive conidia may be produced, and the conidiophore therefore becomes flexuous and irregular. It may also become septate in time. The conidia on both hosts measure ordinarily $28-30 \times 7-9\mu$. They are more or less ovate in form, the basal end being more truncate. They are ordinarily continuous but may become once septate with age. The color is fuliginous or olivaceous, sometimes having a slight reddish tint.

According to Clinton, the conidia are probably unable to retain their vitality for a considerable period of time, and therefore may not be of great consequence in initiating the disease the following season. Some believe, however, that the scabby spots upon old fruits remain living, at least so far as the mycelium is concerned, and that new conidia may be produced the following spring. They would believe that this is particularly true when the fungus has attacked young twigs, and that therefore it is in favorable condition for early infection. Nevertheless, the fungus has not been found constantly or abundantly upon young twigs and it is quite probable that twig infections are less common than is supposed. In that case, the constant reappearance of the disease may be more generally due to the development of the perfect stage during the winter.

So far as the development of the perithecial form has been followed in this country, it is believed that the first evidences of the perithecium in the case of the apple scab are found in October and later, the perithecia reaching maturity by April perhaps. At any rate, mature ascospores have been found during April and May, and the perithecia disappear by the following month. The perithecia are usually found on the under surfaces of the leaves, and Clinton believes that less conspicuous scabby spots develop the perfect stage most freely. The studies which have been made of the perithecia in artificial cultures, strengthened by the observations in the open, seem to indicate beyond any question the relationships of these two forms. The perithecia are somewhat imbedded in the tissues of the leaf, are spherical or nearly spherical in form (Fig. 121), 90 to 150 μ in diameter, and at maturity slightly beaked, these beaks being sometimes protected by half a dozen or more bristles. The perithecial wall is made up of cells more or less polygonal in outline. The asci are clavate to oblong or slightly curved, $55-75 \times 6-12\,\mu$. They are numerous in the perithecia and so far as noted there are no paraphyses. The spores are eight, becoming two-celled, one of which is larger than the other. The spores are olive-brown in color, $11-15 \times 5-7\,\mu$.

The histological development of the perithecium has not been followed. The ascospores germinate readily in water, and sometimes true appressoria are produced, as stated in the case of the

germination of the conidia. The observation has been made (Clinton) that the scab is first seen more abundantly on the lower leaves, and from this the inference is drawn that infection is chiefly as a result of the production of the perfect or Venturia stage on old leaves which have fallen to the ground. The production of the perfect stage is common when the leaves fall upon sod and are more or less protected by their own number or by being partially covered with grass, etc.

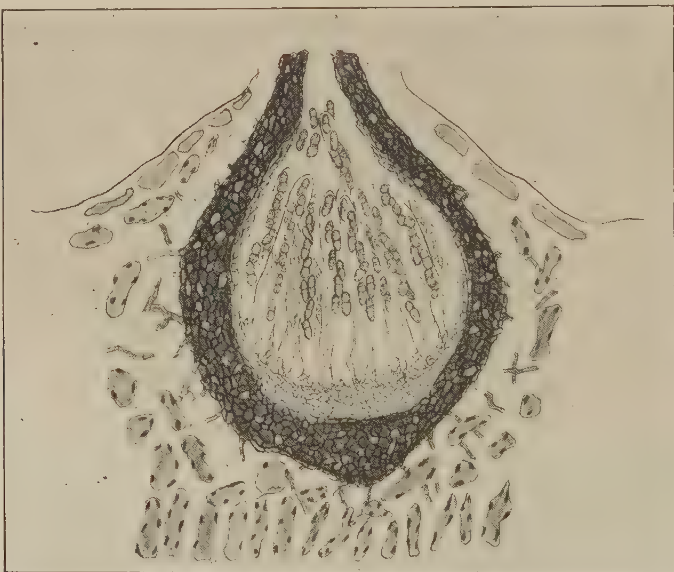


FIG. 121. *Venturia Pomi*, FROM WINTERED LEAVES OF APPLE

Control. In the agricultural experiment stations of the United States spraying experiments have been quite generally conducted looking toward the prevention of apple and pear scab. Some differences in treatment have been recommended for regions where climatic relations are diverse, but in general the method of treatment is much the same. At least one spraying should be made with strong Bordeaux mixture before blossoming. In California it has been recommended to spray twice before the fruit buds have opened; this in case of the pear. A second (or third) spraying may be given immediately after the petals fall, and at

least one more two weeks after the second. The conditions, however, must determine the length of time intervening and the number of applications made.

XLV. BITTER ROT OF THE APPLE AND OTHER FRUITS

Glomerella rufomaculans (Berk.) Spauld. & Von Sch.

BLAIR, J. C. Bitter Rot of Apples. Ill. Agl. Exp. Sta. Bullt. **117**: 483–551. 1907.

BURRILL, T. J. Bitter Rot of Apples. Ill. Agl. Exp. Sta. Bullt. **77**: 351–366. *pl. C. figs. 1–12.* 1902.

BURRILL, T. J. Bitter Rot of Apples. Ill. Agl. Exp. Sta. Bullt. **118**: 554–608. 1907.

CLINTON, G. P. Bitter Rot. Ill. Agl. Exp. Sta. Bullt. **69**: 193–211. *figs. 1–39.* 1902.

CLINTON, G. P. Gnomoniopsis fructigena. Ill. Agl. Exp. Sta. Bullt. **69**: 206–211. 1902.

EDGERTON, C. W. The Physiology and Development of Some Anthracnoses. Bot. Gaz. **45**: 367–408. *pl. 11. figs. 1–17.* 1908.

HALSTED, B. D. Laboratory Studies of Fruit Decays. N. J. Agl. Exp. Sta. Rept. (1892): 326–330.

SCHRENK, H. VON, and SPAULDING, P. The Bitter Rot of Apples. U. S. Dept. Agl., Bureau of Plant Industry, Bullt. **44**: 1–54. *pls. 1–9.* 1903.
(Consult this paper for more complete bibliography on the bitter rot.)

SCOTT, W. M. The Control of Apple Bitter Rot. U. S. Dept. Agl., Bureau of Plant Industry, Bullt. **93**: 1–33. *pls. 1–8.* 1906.

STONEMAN, BERTHA. A Comparative Study of Some Anthracnoses. Bot. Gaz. **26**: 69–120. *pls. 7–18.* 1898. (Glœosporium fructigenum Berk. pp. 71–74. *figs. 1–4, 33–38, 83.*)

The most destructive apple disease in the chief apple-growing districts of the United States is unquestionably the bitter rot. This disease varies greatly in virulence with the conditions, becoming at times so destructive as practically to annihilate a crop in large areas. Fortunately, it does not appear in great quantity until midsummer, and then if the conditions are unfavorable it may not become a source of serious loss.

Distribution. The bitter rot fungus is widely distributed in the United States east of and including Kansas, Oklahoma, and Texas. It seems to be particularly destructive in a more or less central area extending from the Atlantic seaboard in Virginia westward to Oklahoma. The fungus, however, is not limited to the United States, and is probably common and more or less injurious in all apple-producing countries. It is certainly known

throughout Europe, Australia, and in some parts of Asia. The commercial relations between the different countries have doubtless effected its very general distribution. In the United States it has been known for nearly half a century, although it is unlikely that it was a matter of commercial importance prior to the general and widespread development of orcharding, and the consequent more or less contiguous orchard areas. Certainly for twenty years it has been recognized as of serious economic importance in the central area already designated.

Climatic relations. Evidences of the effects of the bitter rot fungus are usually found in July and August, although in the case of early summer apples in the far South, and under exceptionably favorable conditions, it may appear much earlier. In common with most fungi, the favorable conditions are to be found in warm, sultry weather accompanied by rains, conditions so frequent during August in the chief bitter rot regions. During seasons thus characterized the fungus may spread with alarming rapidity, causing enormous devastation within a period of a single week, — this length of time being therefore sufficient under such circumstances for the propagation of the fungus probably through two or more generations. Von Schrenk states that the time of the appearance of the bitter rot is probably influenced by the following factors: (1) age of the fruits; (2) temperature and humidity of the air; (3) presence of spore-distributing centers. The canker areas of the twigs are said to develop somewhat earlier in the season and under less restricted conditions. During cold, dry summers the apple is notably free from bitter rot, even though the fungus may have been unusually common the previous season. Cold weather may act either as a preventive or as a check to the development of the disease after a favorable season for infection.

Losses. It would be impossible to state the average loss sustained by the apple-growing industry throughout the United States as a result of the ravages of this fungus. During years when the disease is prevalent the loss will certainly amount to millions of dollars. The president of the National Apple Growers Association estimated the losses in 1900 at $10,000,000. Burrill reported for the same year a loss in four counties in

Illinois amounting to $1,500,000. Apple growers have become so thoroughly informed as to the destruction of this disease that they have to a large extent adopted the remedies recommended as a result of recent investigations, and steps are now very generally taken to control this fungus. This general interest which has been awakened will doubtless tend to diminish losses in future years.

Parts of the plant affected. Upon the apple the bitter rot fungus is active chiefly as a fruit parasite, although branches may also be affected. The first appearance of the fungus within

FIG. 122. BITTER ROT OF APPLE

the tissues of the fruit is made evident by a small brown spot beneath the skin. In the field, commonly, a single infection, or at most a few infections, are to be found upon one fruit. Under exceptionally favorable conditions, however, numerous infections may occur. In any case, the affected spot may increase rapidly in size, showing constantly a more or less circular outline with a well-defined margin. So soon as the spot has attained a size of one-fourth inch, more or less, the central portion of the affected area is sunken, and this is followed by the further gradual spread of the fungus throughout the fruit, and by the appearance of pustules as subsequently described (Fig. 122). The whole portion of the fruit affected by the fungus is decayed, and

the fruit near a decayed area is invariably bitter. This character, which appears to be quite constant, has given the disease its popular name. Affected fruits usually fall from the trees after a spot has attained considerable size. Nevertheless, in exceptional cases the diseased fruits may hang on, and when the whole fruit has decayed as a direct or indirect effect of the fungus, they become dried, and to these fruits the term "mummy" has also been applied.

The bitter rot fungus has been found upon various varieties of the apple. In some sections it is reported more commonly upon Ben Davis and Grimes Golden, but this may be more particularly due to the fact that these varieties were more generally grown in the regions for which the report was made. The fungus is, in fact, notably unrestricted as to host. The apple is unquestionably the fruit most injured, yet the same fungus may be parasitic upon the grape, peach, pear, tomato, eggplant, and pepper; at least, if infection experiments alone can be trusted to indicate what may take place in nature, the hosts above mentioned, as well as others, are all susceptible.

The fungus. The life history of this fungus includes two stages, one an imperfect fungus, or properly glœosporial stage, which is commonly produced upon the fruit, and the other an ascigerous stage, which may occasionally be produced upon a fruit or twig, and readily developed in artificial cultures.[1] It is believed that the early infection of the fruit frequently arises from the development of pustules bearing conidia in canker areas, the spores falling from the canker areas to the fruit below. It has been frequently observed that affected fruits on a tree may map out a pyramidal area, at the cone of which may be found a cankered limb. Such canker areas (Fig. 123) apparently develop the conidia early in the season. The cankers are in the form of sunken areas upon twigs or limbs, and they are often round or oblong, sometimes several inches long, the bark covering such areas being cracked and broken. The bark readily dries out and

[1] As a result of his studies upon the fungus causing bitter rot Edgerton states: "There are apparently two forms on the apple. These are separated in their geographical distribution apparently by thermal lines; the southern form differs from the northern considerably in cultural characters and it differs also slightly in the characteristics of the perithecium and the acervulus."

adheres closely to the underlying wood. Moreover, tne development of a callus layer at the edge of the dead spot gives a further emphasis to the depression produced by the death and shrinking of the tissues within the canker spots. The canker spots are supposed to persist for at least two years. The mycelium of the fungus may be found in the inner bark and cambium. As previously suggested, the pustules of the fungus break through the bark in these cankered spots early in the season.

Fig. 123. Canker of the Bitter Rot Fungus. (Photograph by Perley Spaulding)

When the fruit spots have attained a size of one fourth inch or more in diameter, there may appear in concentric lines small papillæ, which are in reality the pustules of the fungus. The pustules are formed by the development of a stromatic mass of mycelium beneath the epidermis. From this stromatic mycelium there develops a cone-shaped mass of erect hyphæ which eventually rupture the cell walls. Meanwhile there are produced from the numerous, erect conidiophores an abundance of conidia. When the epidermis is ruptured, these conidia emerge as a waxy, tendril-like strand, which may be at first pink in color, becoming gray with age. The spores are then imbedded in a gelatinous matrix readily soluble in water. Little may therefore be seen of the strand-like production of the spores during moist weather, or even during a period of heavy dews. Fig. 124 shows the relation of the conidiophores to the mycelial stroma. Examined microscopically the conidia are almost hyaline, though having a slight greenish cast. They vary in shape from ovate to oblong, or in some cases even slightly dumb-bell-shape. In general, however, they are ovoidal and vary greatly in size, according to the conditions under which they are

produced. Some observers have recorded extreme sizes, $6-40 \times 3\frac{1}{2}-7\,\mu$. More frequently, however (Von Schrenk), they are $12-16 \times 4-6\,\mu$. The conidia germinate readily, and upon germination almost invariably become septate. Under unfavorable conditions a germ tube may develop at its tip a brown resting cell termed a secondary conidium or appressorium. It is believed that the germ tube may obtain entrance to the fruit through the uninjured skin of the apple, and certainly artificial infection may result without noticeable surface injury. Nevertheless, infection can be hastened by injuring the surface, and it is possible that some slight injury or abrasion may be essential to penetration, although the belief is current that entrance may be effected through the stomates of the fruit.

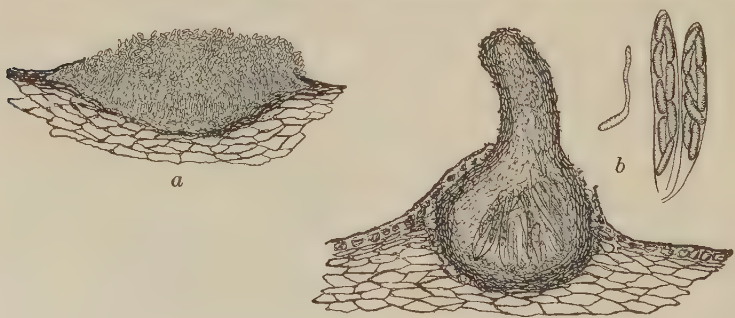


FIG. 124. *Glomerella rufomaculans:* CONIDIAL AND ASCIGEROUS STAGES

This imperfect form was for a long time the only known fruiting stage of the fungus. It was referred to the genus Glœosporium and was generally known as *Glœosporium fructigenum* Berk.

The perithecial stage of this fungus, found by Clinton in 1902, may be readily developed in artificial culture, though Clinton has also reported having found it frequently upon the fruit. In cultures it may be developed within two weeks on various nutrient media, while in nature it develops apparently only the following spring upon fruit which has been upon the ground throughout the winter. In artificial culture the perfect stage develops promptly and vigorously upon apple agar corn meal. The mycelium first forms small black nodules which become stromatic cushions about one fourth inch in diameter. Within this stroma one or many perithecia might be developed. The various stages in the development

of the perithecium have not been very carefully followed, although it would appear that the formation of asci in the perithecium is preceded by a central mass of hyaline cells, which are displaced as the asci arise. At maturity the asci are oblong-clavate, $55–70 \times 9\mu$. Each ascus contains eight spores, frequently arranged in pairs, though sometimes in oblique series. The ascospores are curved, but in general resemble the conidia. They are, however, more uniform in size, being usually $12–22 \times 3\frac{1}{2}–5\mu$. The asci are evanescent, and the ascospores germinate without a period of rest.

It is not believed that the ascus-bearing stage is at all essential to the annual appearance of this disease. It has been frequently shown that the conidia in mummied apples retain their vitality until the following season, and it is probable that infection could result from conidia produced on apples which have remained on the ground throughout the winter. However, when all mummied fruits in the trees as well as under the trees have been carefully destroyed, the disease has been found abundantly the following season. It is therefore probable that a great many infections result through canker spots formed during the summer. These live over winter and produce conidia again during the early summer.

Cultural relations. This fungus may be readily cultivated in the laboratory on almost any of the ordinary nutrient media. Apple agar is especially favorable, but, as already indicated, apple corn meal agar is perhaps as good as any other medium for the production of the ascosporic stage. The conidia germinate within a few hours and the mycelium grows with great rapidity. The mycelium is septate, and neighboring cells of different mycelia readily fuse. In the tissues of the apple the hyphæ are brown with age. In culture, however, the hyphæ are at first only slightly colored. The conidia are produced in quantity in culture, appearing upon an agar plate within twelve hours. Under such conditions the conidia are generally borne upon numerous lateral branches. Upon sterilized fruit in the laboratory the production of conidia within the pustules has required, under the most favorable conditions, only forty-eight hours. It is evident therefore that in the field many generations of this fungus may be produced within a very short time, and that its rapid spread is well explained by the brief period required for spore production.

Control. It is of unquestionable value to keep the orchard as clean as possible of apples affected with the bitter rot fungus, and it is likewise important to prune out all cankered limbs. Nevertheless, these precautions alone are wholly insufficient, and it has recently been demonstrated that the disease may be controlled — at least under the conditions prevailing in the eastern United States — by a proper application of Bordeaux mixture. Under conditions favorable for the spread of the disease, from 93.3 to 98.9 per cent of sound fruit has been harvested upon sprayed trees, while the controls gave practically no fruit of value. It is recommended to make about four applications of Bordeaux mixture, although one or two additional applications may be necessary. In this as in all other such work, the tree should be thoroughly sprayed from a nozzle giving a mist-like application. When spraying for bitter rot alone the first application may be made about forty days after the petals have fallen, subsequent applications being given about two weeks apart. During very wet weather, however, greater frequency may be required, while in cool weather the length of time may be increased. Beneficial results from spraying experiments have also been obtained in the central West, and it is believed that there the disease may be controlled by the methods suggested.

XLVI. ANTHRACNOSE OF SYCAMORE

Gnomonia Veneta (Sacc. & Speg.) Kleb.

EDGERTON, C. W. The Physiology and Development of Some Anthracnoses. Bot. Gaz. **45**: 367–408. *pl. 11. figs. 1–17.* 1908.

KLEBAHN, H. Unters. über einige Fungi imperfecti u. d. zugehörigen Ascomycetenformen. Jahrb. f. wiss. Bot. **41**: 515–558. 1905.

SCRIBNER, F. L. A Disease of the Sycamore. U. S. Dept. Agl. Rept. (1888): 387–389. *pl. 15.*

SOUTHWORTH, E. A. Glœosporium nervisequum (Fckl.) Sacc. Journal Mycology **5**: 51–52. 1889.

Habitat relations. This fungus is parasitic upon the leaves and young shoots of the sycamore or plane tree, *Platanus occidentalis*, and it is widely distributed in Europe and America. In one or more stages the fungus also appears to produce spots upon the leaves of several species of oak, being reported upon *Quercus alba*, *Quercus velutina*, and *Quercus coccinea*. Upon

the sycamore it is in one stage primarily a disease of the leaf veins, although commonly the death of considerable portions of the lamina adjacent soon follows. In another stage the fungus is notably fatal to shoots, young trees, and seedlings. According to Edgerton this fungus may produce in the early spring an effect very similar to frost injury. Indeed, these injuries have been referred by several to spring frosts. On the whole this is one of the most disastrous anthracnose diseases known, and far greater attention would be directed to it if greater concern were felt for the sycamore, which is, nevertheless, a most important shade tree.

The fungus. The interesting life history of this fungus has been carefully worked out. There are three types of imperfect fungi as well as the ascigerous form in the life cycle of this organism. A typical Glœosporium stage (see Glœosporium) appears upon the leaves, and the pustules or acervuli are well developed upon the veins of both the upper and lower surfaces. Upon small, colorless conidiophores ovate conidia are produced measuring $10–15 \times 4–6\,\mu$. The acervuli are from 100 to $300\,\mu$ in diameter, and the spores are produced in such quantity that in moist weather they are forcibly ejected in creamy masses or strings. This stage has long been known to mycologists as *Glœosporium nervisequum*. Upon the twigs the size and type of acervulus has caused the fungus to be referred to the form genus Myxosporium. The further growth of the stroma later in the season may develop the pycnidial or Sporonema stage, in which similar small conidiophores are developed from all sides of a more or less chambered pycnidium. The ascigerous stage is abundantly developed on affected leaves which have wintered over in the open. This stage may appear either during late winter or early spring. The perithecia vary greatly in size, but are ordinarily from 150 to $250\,\mu$ in diameter, with beak $50–100\,\mu$ long. The asci are, according to Edgerton, $48–60 \times 12–15\,\mu$. They are broadly clavate and bent at right angles near the base. The apex is thickened, and there is a terminal pore surrounded by a more refractive ring. The ascospores are invariably eight; they are hyaline, elliptical or arcuate, once septate, and composed of a large upper cell and a small lower. The germ tube emerges invariably from the larger

cell. The various spore forms of this fungus have yielded in culture a perfectly similar mycelium, and infection experiments seem to leave no doubt as to the genetic relationship.

Control. Preventive measures might at least apply to nursery stock and to young trees recently set. It may be supposed that thorough applications of the 5–5–50 Bordeaux very early in the season would greatly assist in the control of this disease.

XLVII. A DISEASE OF YOUNG OAKS

Rosellinia Quercina Hartig

Hartig, Robt. Die Eichenwurzeltödter. Unters. a. d. forst.-bot. Inst. München (1880): 1–32. *pls. 1, 2.*

This fungus occurs as a parasite of seedlings and young oak trees in Germany.[1] It affects primarily the roots and the basal portion of the stem. It has been prevalent in northwestern Germany and particularly disastrous when it occurs in the seed beds. The greater amount of injury results to seedlings from one to three years old. The effects of the fungus are manifest by an unhealthy, pale color of the foliage, followed by withering and wilting of the leaves. Young shoots, and subsequently the older leaves, also wither and die. About the roots and sometimes the lower portion of the stem will be found a felt-like mycelium of interwoven brown threads, or strand-like aggregations.

The perithecia are commonly produced in quantity, particularly after the death of the plant. They are spherical or ovate in form, and brittle in texture, with a papillate ostiolum. The asci are long-cylindrical, each containing eight elliptical or somewhat fusiform, brown or brown-black spores, which are ordinarily vacuolate, and measure $28 \times 6–7\mu$.

[1] One or two other species of Rosellinia have been described as important from the disease point of view. Prillieux (Comp. Rend. **135** : 275. 1902) found a form on the roots of fruit trees accompanying Dematophora, which he considers to be the perfect stage of the latter. He believed that the perithecia were developed on the stroma on which arose the conidiophores. The perithecia measure 1.5 mm. in diameter, are gray-brown in color, with a definite and darker papilla. The body is composed of three wall layers, — the outer indurated and brown, the central white, and the inner yellowish in color. From the latter arise the stalked asci, $365–380 \times 8.5–9\mu$, and small slender paraphyses. The spores long remain colorless, but are finally black with small vacuoles.

XLVIII. BARK DISEASE OF CHESTNUT

Diaporthe parasitica Murrill

METCALF, HAVEN. The Immunity of the Japanese Chestnut to the Bark Disease. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **121**: 55–56. 1908.
MURRILL, W. A. A Serious Chestnut Disease. Jour. N. Y. Bot. Garden **7**: 143–153. *figs. 13–19.* 1906. (Also **7**: 203–211. *figs. 25–30.* 1906.)
MURRILL, W. A. A New Chestnut Disease. Torreya **6**: 186–189. *fig. 2.* 1906.

Occurrence. This bark disease of the chestnut has recently been reported from New York, New England, and other northeastern states, and it would appear that it is spreading rapidly. It is in fact becoming a serious menace to forest tree culture in that section of the country. The common species of chestnut (*Castanea dentata*), seems to be in all localities peculiarly susceptible, and so far as the observations go, all species of the genus Castanea are subject to it with one exception, this exception being certain Japanese varieties of *Castanea crenata* Sieb. and Zucc. Metcalf has found the latter to be quite generally immune, and while the nuts are inferior in flavor to the best European varieties, it is nevertheless an important commercial product. It is hoped that hybridization between the Japanese and American or European forms will be successful in establishing immune varieties with other desirable characteristics of the better sorts. It is not believed, however, that the Japanese chestnut can to any extent replace the native tree for forest purposes, although the former is desirable from an ornamental standpoint. It is suggested that since the Japanese chestnut was first introduced on Long Island, it is possible that Japan may be the home of this fungous pest, and that as a result no resistance could have been developed in the native species.

The fungus. The fungus has been found upon twigs, small-sized branches, and trunks. It completely encircles the affected limbs, and the girdling thus brought about ultimately causes the death of portions beyond, and lessened vitality of the whole tree.

The mycelium of the fungus is confined very largely to the bark and to the underlying cambium. The affected cortex becomes somewhat light brown in color and slightly sunken after desiccation.

Infection does not seem to be possible through uninjured outer bark, but when the latter is punctured or broken, the fungus promptly penetrates the living tissues. It is inferred, therefore, that infection occurs through wounds and possibly through lenticels.

During the summer there is developed through the lenticels from a stromatic mycelium the imperfect stage of the fungus. This latter produces small, rod-like but curved spores, characteristic of the genus Cytospora of the imperfect fungi. These spores are discharged in long, twisted, brownish, thread-like masses. This stage serves for the very rapid propagation of the disease.

During autumn there may be produced from the stroma in the inner bark the perithecial stage. The latter appear in clusters of from ten to twenty. They are flask-shaped with long, slender necks protruding above the surface. The asci are, according to Murrill, $45–50 \times 9\mu$. They are constantly eight-spored, hyaline, oblong, two-celled, and measure $9–10 \times 4–5\mu$.

Control. No practical method of controlling this fungus has been suggested. Severe pruning is certainly advisable if the disease is detected when twigs or branches alone are infested, and it is possible that systematic effort may hold the disease in check, even where the conditions are favorable for its spread. Spraying is perhaps impracticable.

XLIX. BLISTER CANKER OF APPLE

Nummularia discreta Tul.

HASSELBRING, H. Canker of Apple Trees. Ill. Agl. Exp. Sta. Bullt. **70**: 225–239. *pls. 1–4.* 1902.

The blister canker of the apple is well distributed throughout the apple-growing region of the Mississippi Valley, and doubtless in other sections of the United States. It also occurs in Europe, but has not been reported as a disease worthy of special consideration. This canker, like others already described, is, however, a source of constant danger on account of the fact that it is perennial in the host and in time is sure to cause the death of large limbs or of the entire tree. The blister canker has been termed the Illinois canker, since it was first observed as particularly

destructive in that state. Under ordinary circumstances the fungus is doubtless a mere saprophyte, and it is not restricted to the apple or to other members of the apple family. It has in fact been found upon such trees as the following: American elm (*Ulmus americana*), *Magnolia* sp., Judas tree (*Cercis canadensis*), and *Sorbus* sp.

Symptoms. The disease is usually found upon the larger limbs or upon the trunk, and the appearance of the canker areas is so characteristic that it cannot be mistaken, at least in late stages of the disease, for any of the cankers thus far discussed. At first the infested areas are brown, slightly sunken, and consist of small spots of healthy tissue intermingled within the general diseased area. These die later, but there is an irregular and mottled effect which persists and is readily observed. The infected area may cover many square inches of surface, and it is sharply delimited from the healthy tissue, due to the drying and cracking. Occasionally there is a slight development of slime during the early part of the season, but this has not been associated with the action of the parasite.

FIG. 125. BLISTER CANKER OF APPLE

Hasselbring describes the external appearance during the late season as follows:

The bark of the older parts becomes much roughened and blackened as if it had been charred. Numerous rifts and cracks appear over the surface of the dead bark, which is very dry and brittle, and falls off in irregular patches, exposing the dead wood. The circular stromata are firmly attached to the wood by means of a ring of hard fungous tissue, so that they remain seated on the wood even after the bark has fallen away. The entire blackened area is dotted over with the circular stromata, which form the most pronounced distinguishing feature of this canker. The disease is always easily recognized by these stromata (Fig. 125), which distinguish it clearly from the New York apple tree canker.

The fungus. The mycelium penetrates the bark and later the wood beneath to a considerable extent. The course of the fungus through the bark and wood is very largely through the parenchymatous and medullary cells. From these, however, it infests neighboring tissues, especially the xylem vessels. The stromata and fruit bodies are developed from the latter part of the summer into the autumn and winter. From the upper surface of the stroma a mat of conidial hyphæ arises. These break through the epidermis and underlying fungous tissue. The conidia are simple, hyaline spores which apparently do not readily germinate. Later in the season the underlying stromatic tissue which is now cup-shaped shows the development of flask-shaped perithecia sunken in that portion of the stroma which is made up chiefly of fungous tissue. Bordering the stroma a black line of more abundant fungous tissue is also evident. The body of the perithecium is elliptical or ovate at maturity, and it is completely filled with long-cylindrical asci about $160 \times 13 \mu$. The asci are thick-walled with terminal pore, and contain at maturity eight more or less spherical, brown spores. The latter often measure $13 \times 10 \mu$, and a clear space along one side indicates the line of rupture during germination. Twin germ tubes are invariably developed.

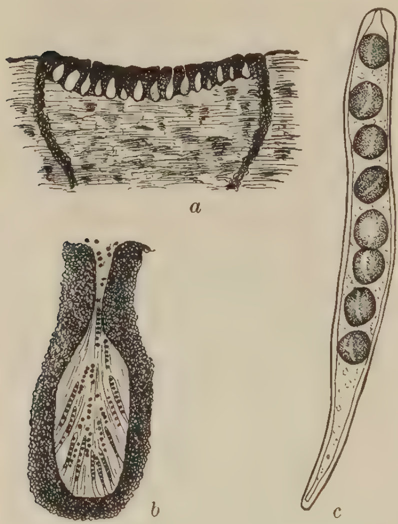


FIG. 126. *Nummularia discreta*: the Blister Canker Fungus

a, stroma; *b*, perithecium; *c*, ascus

Control. Observations on the progress of this disease would seem to indicate that this fungus gains entrance through wounds, and prevention consists in avoiding as far as possible the improper injuries due to careless methods of pruning, cultivation, and harvesting. Moreover, the cankered areas on limbs should be pruned out and destroyed when found.

CHAPTER XII

FUNGI IMPERFECTI

The imperfect fungi, or fungi imperfecti, constitute an heterogeneous subdivision of the true fungi. As a class it is not comparable to the natural classes thus far discussed, yet it may be given an equivalent name and regarded as a coördinate division for the sake of convenience in general treatment and classification. The fungi thus brought together consist of species having hyphomycetous, melanconiaceous, or sphæropsidaceous types of spore production. Since these types may represent special "stages" in the life cycles of other fungi, these secondary fruit forms in general will not permit of certain classification under the groups thus far discussed, much less under the Basidiomycetes subsequently treated. The great majority, however, and perhaps all of those here discussed would unquestionably find their natural relationships with various genera of the Ascomycetes, and for that reason they are conveniently treated as following that group. Some of the Hyphomycetes in general, however, might represent imperfect forms of the Phycomycetes or even of the Basidiomycetes. In any case it would generally be impossible to determine the genus or even the family in which a particular imperfect fungus or form genus might be placed. It is therefore essential to have such form genera, under which species may be described and classified until their complete life cycles are known, when they may be transferred to the proper natural genus (genus of so-called perfect fungi). In many other minor ways the form genus is a matter of convenience and certainly contributes some stimulus for a better description of the different spore forms in the polymorphic species.

Among the imperfect fungi, as here interpreted, three chief subdivisions are generally recognized, as follows:

Hyphomycetes — conidia borne upon exposed conidiophores which may be single, fascicled, or united together in a columnar or tubercular fashion.

Melanconiales — conidia borne on relatively short conidiophores arising from or within a more or less differentiated stroma, produced usually beneath the epidermis.

Sphæropsidales — conidia borne on short conidiophores arising within a perithecium, or pycnidium, or sometimes within cavities of a dense stroma.

The primary subdivisions of these groups are termed families, and in the case of the Sphæropsidales this classification is based on characters more or less comparable to those separating certain orders or families of the Ascomycetes. The secondary and further subdivisions down to the genera are properly an artificial classification based chiefly upon the color of the spores and the extent of septation. Details of this classification may be found in the taxonomic works; but a brief comparison of important genera embracing parasitic species is here included.

I. HYPHOMYCETES

1. (*Mucedineæ;* mycelium and spores generally light colored.)

Oospora. In this genus the vegetative mycelium is delicate and inconspicuous. The conidia are relatively numerous, ovoidal to spherical in form, hyaline, and unicellular (amerosporic).

Monilia. In this case the vegetative hyphæ are more evident and the fertile hyphæ are branched, often in dense clusters, with hyaline or slightly colored conidia produced in chains. To this form genus the conidial stage of the brown rot of stone fruits may be referred (cf. *Sclerotinia fructigena*).

Oidium. As generally interpreted this genus includes among its representatives the conidial stage of Erysiphaceæ (cf. page 215). The powdery mildew of the vine was long known only as *Oidium Tuckeri.* The conidia are produced in chains on short, erect hyphæ generally arising from a superficial mycelium.

Sporotrichum possesses an extensive mycelium and conidiophores which are, as a rule, well differentiated. The latter are branched and bear numerous, hyaline, one-celled, more or less spherical conidia. These originate from tips of branches or on minute sterigmata. Some species of this genus parasitic or saprophytic upon insects are connected with a compound form, Isaria, and an ascigerous stage, Cordyceps.

Botrytis. This genus, although somewhat indefinitely characterized, differs from the preceding chiefly in having spores grouped at the tips of branches and ordinarily borne on papillæ or tooth-like projections.

Cephalothecium is characterized by relatively long, unbranched, upright conidiophores, at the tip of each of which may be produced a cluster of two-celled, hyaline (hyalodidymic), usually pear-shaped conidia.

Ramularia. The mycelium is wholly within the tissues of the host, the conidiophores are hyaline, straight or flexuous, single or fascicled. The conidia are single or loosely adherent in chains. They are narrowly elliptical to cylindrical, and divided into three or more cells (hyalophragmic).

Cercosporella. This genus is related to the preceding on account of its hyaline conidiophores and conidia, but on the other hand it is very close to Cercospora, subsequently described, on account of the filiform spores (scolecosporic) and sometimes geniculate conidiophores.

Piricularia differs from the preceding genus in having conidia which are strongly obclavate to pyriform and generally pluriseptate.

2. (*Dematieae;* mycelium dark, at least with age; spores generally dark.)

Fusicladium. The mycelium produces short conidiophores which may be single or in small clusters. These produce at the tips elliptical conidia which at maturity are two-celled and colored (phæodidymic) (cf. Venturia, page 264).

Polythrincium differs from the last-mentioned genus chiefly in the nodulose or twisted conidiophores.

Scolecotrichum. These forms possess, instead of nodulose conidiophores, those which are geniculate, a knee being formed as the conidiophore is prolonged by growth on one side of each spore successively produced. The spores are more or less elliptical and two-celled.

Cladosporium. In this genus there is less regularity in the form of the conidiophores and the sizes of spores, as the conidiophores are considerably branched, and these branches may become spores. The conidiophores are olivaceous, also the ovate, eventually two-celled conidia.

Helminthosporium possesses straight, dark colored conidiophores bearing club-shaped or spindle-form, many-celled, flavous to dark colored conidia (phæophragmic).

Macrosporium. In this genus the straight conidiophores bear ovoidal or elliptical spores which are transversely septate, and many of the cells thus formed become longitudinally, and then even again transversely, divided (dictyosporic).

Alternaria differs from the previous genus particularly in having the conidia borne in chains, and these conidia are often clavate in form.

Cercospora possesses straight, flexuous, or strongly geniculate conidiophores, which may be single or grouped. The conidia are needle-shaped or filiform (scolecosporic), hyaline to considerably colored, and from three to many times septate. This is one of the largest genera of the Hyphomycetes, containing about five hundred described species, more than three fourths of which are attributed to North America. All species are parasitic.

3. (*Tuberculariæ;* conidiophores in the form of a tuberculate mass, or sporodochium).

Volutella. In this genus the sporodochium, or fruiting tubercle, is a more or less closed, disciform body, not, however, produced on a basal stroma. It is provided, around the border, with hair-like setæ. The conidiophores are mostly unbranched and give rise terminally to hyaline, unicellular conidia.

Fusarium. In this genus the sporodochia are small cushion-like masses of interwoven hyphæ which may appear waxy or filamentous in texture. The conidiophores proper are unbranched, and they bear successively at the tips curved or sickle-shaped, hyaline, many-celled (at maturity) conidia.

II. MELANCONIALES

Glœosporium. The spore-producing pustule, or acervulus, may be extensive, and is made up of a mass of relatively short conidiophores arising from, and commonly partially inclosed within, a stromatic cushion of fungous tissue. At maturity the stroma opens, and thus it ruptures the epidermis. It may even expand so widely as to seem to constitute merely a basal stroma. The spores are ovoidal, fusiform, or slightly curved, and hyaline

(hyalosporic). There are supposedly about three hundred species, all of which are parasitic. Some species are connected with Glomerella or related genera (cf. *Glomerella rufomaculans*, page 271).

Colletotrichum, including about forty species, has characters similar to the preceding except that the acervuli are bordered by from few to many dark, rigid setæ, usually several times the length of the conidiophores.

Marssonia is a genus similar in development to Glœosporium except that it possesses, as a rule, less extensive acervuli, two-celled (hyalodidymic) spores, and it occurs on leaves only.

Septoglœum is another genus of the Glœosporium type except that the long-elliptical or cylindrical conidia are pluriseptate.

Coryneum is characterized by simple conidiophores and dark, triseptate or pluriseptate conidia (phæophragmic) without appendages of any kind. The conidia are not set free in horn-like or tendril-like masses.

Pestalozzia is readily distinguished by the peculiar conidia, which are more or less elliptical, triseptate or pluriseptate, the apical and basal cells being hyaline or very light colored, and the central cells dark. The apical cell is provided with one or more filiform appendages. The conidiophores are also filiform.

Cylindrosporium is comparable to Septoglœum except that the spores are filiform or needle-shaped, usually curved and continuous.

III. SPHÆROPSIDALES

Phoma. In members of this genus the pycnidia are single, or sometimes closely aggregated. They are immersed in the tissues of the host until maturity, when the epidermis is ruptured. The conidia are small, hyaline, usually ovate or elliptical, and continuous. The genus is arbitrarily limited to those species having spores less than 15 μ, larger forms being relegated to Macrophoma. Species of Phoma inhabit fruits, twigs, or, in some cases, all parts of the hosts, but they are considered to produce no definite spots. About eleven hundred species of this genus are recognized, but relatively few of these have been determined by broad comparison or careful cultural studies.

Phyllosticta applies to species similar, morphologically, to those in the preceding genus. Phyllosticta, however, produces definite

spots and inhabits leaves only. This is also a very large genus, consisting of about eight hundred species.

Forms of both Phyllosticta and Phoma, occurring on the grape, have been found to be stages of a Guignardia. Some species of Phoma would seem to be imperfect stages of Diaporthe, and others have been associated with still other ascigerous forms.

Sphæropsis includes species with relatively large, continuous, colored conidia (phæosporic). The conidia are generally elliptical. The pycnidia are at first immersed and finally break through the epidermis. They are black with papillate ostiolum. There are nearly two hundred species of this genus, of which a few are important parasites.

Coniothyrium, which includes nearly as many species as Sphæropsis, differs from the latter chiefly in the smaller size of the spores, which, moreover, are often less colored.

Septoria. In this genus the pycnidium resembles closely that of Phyllosticta or Sphæropsis, but the spores are long and filiform, often slightly curved, usually pluriseptate. With respect to spore characters, therefore, the genus corresponds more or less to Cercosporella and Cylindrosporium of the imperfect fungi here described.

Leptothyrium is characterized by a more or less superficial, shield-shaped, black pycnidium without definite ostiolum. The spores are one-celled and hyaline.

Entomosporium possesses relatively large, black pycnidia without ostiola. The spores are four-celled in the form of a cross, the horizontal cells smaller. Each cell is provided with a delicate awn-like appendage.

IV. POTATO SCAB

Oospora scabies Thaxter

STURGIS, W. C. On the Susceptibility of Various Root Crops to Potato Scab, etc. Conn. (N. H.) Agl. Exp. Sta. Rept. **20**: 263–266.

THAXTER, ROLAND. The Potato "Scab." Conn. Agl. Exp. Sta. (1890): 81–95.

THAXTER, ROLAND. The Potato Scab. Conn. Agl. Exp. Sta. (1891): 153–160.

The scab of potatoes is a disease which is well known to growers, dealers, and consumers alike, for the conspicuous scab pits or spots on the surface of tubers cannot fail to strike the attention.

The disease is most common throughout the United States, and doubtless throughout the potato-producing regions of Europe as well. It is not positively demonstrated, however, that all of the surface injuries known as scab are properly referable to the fungus here discussed as the causal organism, yet it is highly probable that potato scab as a common disease is generally due to *Oospora scabies*.

Sturgis and others have found turnips (*Brassica campestris*), beets, and mangels (*Beta vulgaris*) susceptible to this disease. Carrots (*Daucus Carota*) and parsnips (*Pastinaca sativa*) are not regarded as susceptible. It is possible, moreover, that this fungus

FIG. 127. POTATO SCAB

may occur upon the less conspicuous roots of some other plants, but it is typically a disease of fleshy roots.

Before the scab organism had been isolated and careful inoculation experiments made, a great variety of causes were assigned by observers and investigators, various bacteria and fungi, also insects and myriapods being held responsible for these injuries.

The result of Thaxter's studies in 1890 furnished proof that the common form of scab in New England is caused by a minute parasitic fungus tentatively designated as above. The disease[1] "first shows itself as a minute reddish or brownish spot on the surface

[1] Thaxter, *l. c.*, 1890.

of the tuber, often making its appearance when the tuber is very young, and sometimes not until it has reached a considerable size. This discoloration very commonly, though not invariably, has its origin in one of the roughened points, or lenticels, which are scattered over the surface of the potato, and after it has once appeared may extend quite rapidly to the adjacent tissue, becoming deeper in color and being associated with an abnormal corky development of the parts involved, which often cover a considerable area. This area may constitute a more or less irregular scab-like crust over the surface, or more frequently may become deeply cracked and furrowed, the depth and extent of the injury depending in a great measure upon the stage at which the tuber first became diseased; those which are attacked while very young showing, as might be expected, by far the most deep seated injury" (Fig. 127).

FIG. 128. A SUGAR BEET AFFECTED WITH SCAB

If scabby potatoes are carefully harvested and immediately examined, there will be found associated with the disease an evanescent grayish film. This film is made up of extremely delicate, minute, refractive, branched filaments, which break up into bacterioidal cells. Some branches are curved, and spore-like structures are also produced within certain cells.

Experiments demonstrate that the fungus may persist in the soil several years. A few scabby potatoes are sufficient to spread the organism to a bin of clean tubers. To secure potatoes free of scab, clean tubers should be planted in soil free from the fungus.

Control. Abundant experimental work has shown that of the two possible lines of control, soil treatment or seed treatment, the latter is most effective; and this, together with a judicious rotation of crops, is sufficient permanently to control this disease. The method of treating the seed tubers consists in immersing them for two or more hours in a solution of 1 ounce of formalin to every 2 gallons of water, or in a solution of bichloride of mercury, consisting of 1 ounce to 8 gallons of water.

V. BUD ROT OF CARNATIONS

Sporotrichum Poæ Pk.

HEALD, F. D. The Bud Rot of Carnations. Neb. Agl. Exp. Sta. Bullt. **103**: *pls. 1–8.* 1908.

STEWART, F. C., and HODGKISS, H. E. The Bud Rot of Carnations and the Silver Top of June Grass. N. Y. (Geneva) Agl. Exp. Sta., Tech. Bullt. **7**: 83–119. *pls. 1–6.* 1908.

Habitat relations. The bud rot of carnations has recently received careful attention as of importance in some of the greenhouses of New York, Illinois, and Nebraska. In cases where the infection is late in developing, or where the conditions are unfavorable for the fungus, the infected flowers may be only slightly abnormal or disfigured. Even in these cases, however, the petals become eventually discolored, and the death of the calyx also ensues. In severe attacks, or under favorable conditions for the fungus, there is developed within the bud a soft rot, resulting in discoloration of all the parts. Occasionally the evidences of fungous growth are sensible to the unaided eye.

Commonly there is associated with the fungus a species of mite. According to the experimental evidence, this mite has no causal connection with the disease, but it is doubtless of importance in the distribution of the fungus. In an early stage of the attack, the mites are extremely minute, and might be overlooked; but later the distention of the mite body makes it an object of such size that it may not be overlooked even upon casual observation. Experiments have clearly indicated that the fungus is able to produce the disease when inoculated in the young buds by needle prick or scalpel wound.

The fungus has been isolated and can be readily grown in artificial media. Upon starchy media, or media containing considerable sugar, it produces a very vigorous growth, often cottony in appearance. Glucose agar, corn meal, etc., are colored pink, or some shade of deep red after growth of a week or more; but the color is less intense when the fungus is grown on starchy products, apparently, than on a glucose agar.

The fungus. It produces two forms of conidia, which have been designated microconidia and macroconidia (Fig. 129). The microconidia are more or less subspherical, or slightly pointed at the base, even pear-shaped, and they are produced by a constriction from lateral or terminal branches, the latter being sometimes clustered. Each branch may produce a large number of conidia by successive abscision, and the conidia frequently become massed together in balls. They vary from 5.5 to 8 μ in diameter, and are capable of immediate germination, producing a much branched mycelium. The macroconidia are far less frequent in culture and in nature than the microconidia. The method of production of the former type is practically the same as in the case of the microconidia. There is, however, greater vacuolation of the protoplasmic contents during the formation of the macroconidia, which, moreover, may become ovoidal, and finally further elongate, becoming once or more septate. They measure $4.5–5.8 \times 10–17.5\,\mu$. Owing to the fact that the conidia are in general microconidia, properly the type of the genus Sporotrichum, this fungus is retained in that genus.

FIG. 129. *Sporotrichum Poæ*: CONIDIOPHORES AND CONIDIA

Control. This disease is often one of serious importance in well-arranged and sanitary carnation houses; but it is apparently most to be feared where conditions for forcing the host are desired, or where unsanitary conditions prevail. Control or prevention

therefore concerns itself primarily with a maintenance of conditions as dry and cool as is compatible with satisfactory growth, and also with matters of general sanitation, such as proper ventilation, destruction of diseased parts, and all defective specimens, leaves, and other refuse. Affected buds should also be picked off and burned. Susceptible varieties should not be grown where the disease prevails.

VI. A PINK ROT FOLLOWING APPLE SCAB

Cephalothecium roseum Cda.

CRAIG, JOHN, and VAN HOOK, J. M. Pink Rot. An Attendant of Apple Scab. Cornell Univ. Agl. Exp. Sta. Bullt. **207**: 199–210. *figs. 36–40.* 1907.

EUSTACE, H. J. A Destructive Apple Rot Following Scab. N. Y. Agl. Exp. Sta. Bullt. **227**: 367–389. *pls. 1–8.* 1902.

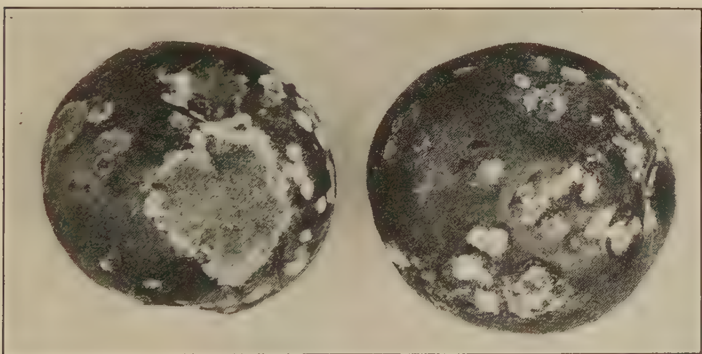


FIG. 130. PINK MOLD FOLLOWING APPLE SCAB. (Photograph by John Craig)

During several seasons, particularly the autumn of 1902, apple scab was very prevalent in western New York, favored by a moist, muggy season. The scab was followed in the autumn by the development of a mold upon the scab spots (Fig. 130), which was at first white, becoming pink with a production of abundant spores. The fungus was identified as above, and proved to be common in many orchards of the state. It is a widely distributed saprophyte, which can be expected perhaps to cause widespread injury only when conditions are unusally favorable for its development. The greatest damage is done after harvesting, and the Rhode Island Greening has proved to be the variety most susceptible to its attack.

Inoculation experiments have also indicated that this fungus may produce a rot through wound infections on apple, pear, quince, and grape. It is believed that the fungus will become injurious only under the conditions mentioned, and, therefore, it is necessary to take indirect precautions only. Prevention of the scab, in particular, will mean prevention of this rot, which is secondary to it.

VII. RAMULARIA

While the genus Ramularia is entirely parasitic, few plant diseases of serious consequence are produced. Reference has already

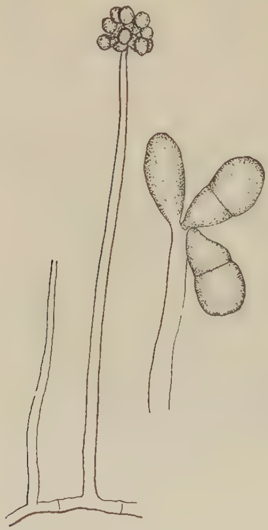


FIG. 131. *CEPHALOTHECIUM ROSEUM*

FIG. 132. AREOLATE MILDEW OF COTTON

been made to *Ramularia Tulasnei* (see *Mycosphærella Fragariæ*, page 261).

Ramularia areola Atk. This fungus, producing what may be known as the frosty blight or "areolate mildew" of cotton, is very characteristic. Small areas of the leaf between the finer veinlets are occupied by the fruiting hyphæ. The latter are fascicled, and numerous spores are borne. As a result of the abundance of the fruiting hyphæ and the avoidance of the veins an areolate appearance is presented (Fig. 132).

Ramularia rufomaculans Pk. This Ramularia produces on the leaves of buckwheat (*Fagopyrum esculentum*) blotch-like areas covered with abundant conidiophores. In appearance it is therefore very much like the form on cotton.

VIII. CERCOSPORELLA

Cercosporella Persicæ Sacc. The frosty mildew of the peach in the United States is far more common from Maryland southward. It forms on the under surfaces of the leaves conidiophores and conidia in such quantity as to give the appearance of a surface mildew. It is most prevalent and often a serious disease in moist regions, but may be readily controlled by early spraying.

IX. RICE BLAST

Piricularia grisea (Cke.) Sacc.

FULTON, H. R. Rice Blast. La. Agl. Exp. Sta. Bullt. **105**: 1–12. *figs. 1–12.* 1908.
FARNETI, R. Rivista Patalog. Veg. **2**: 1–11, 17–42.
METCALF, HAVEN. Preliminary Report on the Blast of Rice. S. C. Agl. Exp. Sta. Bullt. **121**: 1–43. 1906.

Habitat relations. The blast of rice (*Oryza sativa*) is reported from the most important rice-growing regions, and would appear to be a common disease wherever rice is cultivated. It causes no small annual loss, and the outbreaks are frequently severe. Up to the present time there is very little unanimity in the opinions expressed with respect to the factors conditioning epidemics. After an analysis of diverse conditions reported as operative, Fulton believes that the factors are far more complex than generally stated. In South Carolina it seemed that unfavorable soil conditions are important, and in Italy lack of root aëration is suggested as the cause of "brusone," a disease with which the Piricularia is at least associated.

Under favorable conditions there is a marked difference in the susceptibility of diverse rice varieties. At the present time it would seem that there are no varieties wholly free from the disease.

Symptoms. The fungus attacks leaves and stems. Upon young plants the older leaves are first affected and later the younger portions of the plant. The young leaves become rapidly pale in the

affected areas and then water-soaked, dark and dead. Conspicuous lesions occur at the sheath nodes and upon the stems. When the disease appears at or above the topmost stem node, it is generally most serious. The maturing heads droop or fall to the ground. Leaves affected at the tip of the sheath also hang downward. Old leaves may develop spots with ash-colored centers and bright brown borders.

The fungus. Conidiophores and conidia of the fungus may be found abundantly upon the affected parts in moist weather. The former emerge from the stomata, generally in clusters of two or three. They are ordinarily simple, fuliginous in color, septate, and they bear in succession several conidia, each from a tip which is for the time terminal. The spores are ovate, two-septate, and measure $24\text{–}29 \times 10\text{–}12\,\mu$. Careful inoculation experiments have shown that the fungus is able to induce the disease in uninjured, growing plants of various ages. The fungus on rice was described as *Piricularia Oryzæ* Briosi & Cavara, but the evidence available indicates that the fungus concerned is identical with *Piricularia grisea*, as above given. The latter is the name applied to the fungus occurring in many regions upon the crab grass (*Panicum sanguinale L.*).

Control. It is unquestionably important in rice culture to provide the most favorable conditions for a vigorous growth of the rice plant, and at present other direct preventive measures seem impracticable. It would seem that varietal resistance will in time offer the safest means of control.

X. POLYTHRINCIUM

Polythrincium Trifolii Kze. **Sooty spot of clover.** This fungus is very generally distributed upon certain species of clover, notably red clover (*Trifolium pratense*), in many parts of the world. The wavy or spiral character of the conidiophores and the sooty or fuliginous color of conidia and conidiophores are characteristic. This species is the only one which has been described in the genus. On account of the characteristics and habits of the mycelium and of the stroma sometimes produced, it has been assumed that the perfect stage would be a species of Phyllachora, and the plant actually bears also the name *Phyllachora Trifolii* (Pers.) Fckl.

XI. PEACH AND APRICOT SCAB

Cladosporium carpophilum Thüm.

ARTHUR, J. C. Spotting of Peaches. Ind. Agl. Exp. Sta. Bullt. **19**: 1–8. *figs. 1–3.* 1889.
CHESTER, F. D. Peach Scab. Del. Agl. Exp. Sta. Rept. **8**: 60–63. 1896.

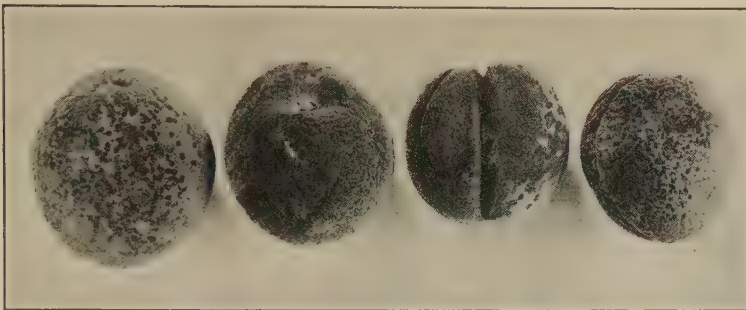


FIG. 133. PEACH SCAB ON WHITE-FLESHED FRUIT

This fungus is responsible for the well-known peach scab, a disease common throughout the country on peaches, and also on apricots. It forms, as a rule, numerous small, circular, sooty spots, sometimes confined to one portion of the fruit and at other times scattered over the whole surface. It is so common upon the poorer grade of market fruit that during an ordinary season practically none of the second or third quality fruit, especially that with white pulp, is free from it. The spots may become scabby in form, and coalesced into large irregular areas, and as a result of the injury severe cracking of the fruit may occur (Fig. 133). Twigs and leaves may also become affected. On the latter distinct spots are produced, often accompanied by the falling out of the affected areas, as with many other fungi, thus leaving a shot-hole effect. On the twigs the

FIG. 134. *CLADOSPORIUM CARPOPHILUM*

fungus may be perennial in brown or purplish-brown spots, and from such areas the conidial stage of the fungus is produced the following spring. The fungus, shown in Fig. 134, is known only by the conidial stage, and the latter is developed throughout the season. In artificial culture this Cladosporium grows readily, producing a dense olive-black mycelium, with somewhat abnormal conidiophores and conidia, but no other stage has been reported in such cultures.

XII. CLADOSPORIUM: OTHER SPECIES

Cladosporium Cucumerinum Ell. and Arth. This fungus, like many other species of the genus, is occasionally parasitic. It occurs upon melons, producing sunken spots on the fruit, and sometimes on the stems. This trouble is apparent, as a rule, only during very moist weather, and under such circumstances the conidial stage of the fungus is developed abundantly over the affected areas, which appear olivaceous in color (Fig. 135).

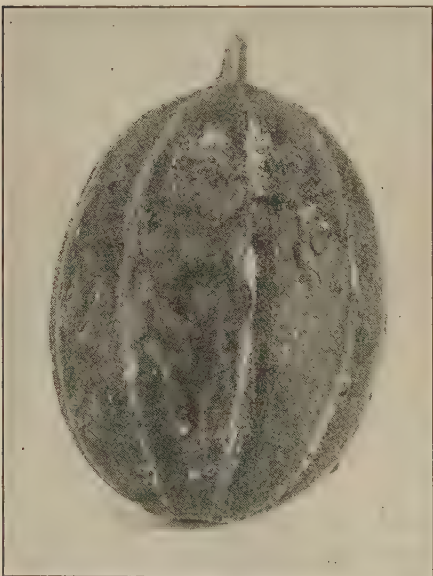


FIG. 135. *CLADOSPORIUM CUCUMERINUM* ON MELON

Cladosporium fulvum Cke. **Leaf mold of tomato.** This fungus is common during moist weather, producing on tomatoes a leaf blight which shows itself in its effects upon the upper surface by a moderate yellow discoloration, which may eventually appear as true spots. On the under surface the olivaceous growth of the fungus may be seen. As the disease progresses the entire leaf may become yellowed, and often whole plants may be defoliated. The fungus is an active parasite, although belonging to a genus most of the members of which are saprophytic in habit.

XIII. EARLY BLIGHT OF THE POTATO

Macrosporium Solani E. & M.

CHESTER, F. D. A Leaf Blight of the Potato. Del. Agl. Exp. Sta. Rept. **4**: 58–60. 1891.
GALLOWAY, B. T. The Macrosporium Potato Disease. Agl. Sci. **7**: 370–382. 1893.
JONES, L. R. Potato Blights. Vermont Agl. Exp. Sta. Rept. **9**: 66–88. 1895.
JONES, L. R. Certain Potato Diseases and their Remedies. Vermont Agl. Exp. Sta. Bullt. **72**: 1–32. 1899.
JONES, L. R., and GROUT, A. J. Notes on Two Species of Alternaria. Bullt. Torrey Bot. Club **24**: 254–258. 1897.
STEWART, F. C., EUSTACE, H. J., and SIRRINE, F. A. Potato Spraying Experiments in 1906. N. Y. (Geneva) Agl. Exp. Sta. Bullt. **279**: 155–229. 1906.
STURGIS, W. C. Notes on "Early Blight" of Potatoes. Conn. Agl. Exp. Sta. Rept. **18**: 127–135. 1894.

Habitat relations. The fungus causing the early blight of potatoes was described in 1882. In 1891 it was recorded as of economic importance in the United States, but subject to control. Since that time this fungous disease has grown constantly in importance, although to a very large extent preventable. The early blight is common practically throughout the United States, and it occurs also in Canada, Europe, Asia, and Australia.

In temperate regions the leaf blight may be found from July to the end of the growing season, increasing generally as the season advances. It may be checked, however, by periods of unusual drought, but it does not appear to be easily affected by lesser changes in conditions.

This disease is a typical leaf blight and may be distinguished from the late blight already described and from such nonparasitic pathological conditions as tip burns and sunscald by recognizable leaf characters. The spots are brown, circular, or elliptical, and they are distinctly marked with concentric or target-board markings. They are irregularly distributed over the leaf surface, although frequently occurring upon the borders of other injuries (Fig. 136). Through carefully conducted experiments (Jones) it has been satisfactorily determined that the fungus may establish itself by truly parasitic means, being capable of infecting healthy leaves, provided only that sufficient moisture is present to insure germination and vigorous growth. Nevertheless, the fungus is

encouraged by certain weakening influences, such as the age of the leaf, the presence of flea-beetle injuries, etc. When large spots near the margins of the leaves become confluent, such extensive areas are affected that there may result a rolling up of the edge, which might be mistaken for the tip burn, a disease generally due to climatic conditions.

The injury from the early blight results, therefore, in an early death of the leaves, as a result of which the vines dry up and the losses to the growing crop are often very considerable, amounting to as much as 50 per cent. The disease is said to be more likely to begin at the time of flowering and while the work of the plant is directed toward the development of tubers. This fungus produces no rot directly.

FIG. 136. EARLY BLIGHT OF THE POTATO

This Macrosporium is found not only upon the potato but also upon tomatoes and upon the jimson weed, (*Datura Stramonium*). There is also a very considerable difference in the susceptibility of the different varieties of potato, but at present no wholly resistant sorts are known, although the general question of the resistance of potatoes to diseases is receiving special attention in the chief potato-growing regions of the world.

The fungus. Within the tissues the mycelium is light brown to olivaceous, and the conidiophores arise through stomates or push up between the collapsed epidermal cells as erect or assurgent fruiting hyphæ $50–90 \times 8–9\,\mu$. They are septate, slightly curved, and, as is characteristic of this genus, the conidia are produced singly, so far as observed, upon the host. The conidia have been described as "obclavate, brown, $145–370 \times 16–18\,\mu$, terminating in a very long, hyaline, septate beak (apical cells) equalling fully one-half the length of the spore (often exceeding this); body of spore with 5 to 10 transverse septa, longitudinal septa few or lacking" (Fig. 137).

The germ tubes arise from any cell of the spore, and it is stated that they may enter the host either by means of the stomates or by directly penetrating the cuticle. This fungus grows vigorously in pure cultures. Upon prune agar it has been found (Jones) that the spores might be produced as a chain of two, and on account of this character the plant has been placed in the related genus Alternaria. As is, of course, well known, the step from Macrosporium to Alternaria is at best a very slight one, yet it should be remembered that these genera based upon recognizedly variable characters serve at most for convenience. The catenulate method of spore production has been reported only in artificial cultures in this case, and it is possible, furthermore, to obtain for various fungi in such cultures in general many variations from what would be considered the normal type of spore production upon the host. Attention may be called to the fact that cultures of many Stilbeæ yield upon agar only simple conidiophores. Cultures of Fusarium and Glœosporium are also modified in an equivalent manner, the stromatic development being usually suppressed. Species of Cercospora also produce spores in an abnormal manner. Upon the leaf Macrosporium may be accompanied by one or more species of true Alternaria, but the latter are saprophytic, as determined by experimental work.

FIG. 137. *MACROSPORIUM SOLANI:* GERMINATING SPORES WITH HYPHÆ ENTERING STOMATA (After Jones)

Control. Wherever careful spraying experiments have been made it has been found possible in ordinary seasons to reduce the injuries from the early blight to a very small minimum by the same method which has been recommended in case of the late blight and rot.

XIV. ONION MOLD

Macrosporium Sarcinula Berk.

MIYABE, K. On the Life-History of Macrosporium parasiticum Thüm. Ann. Bot. **3**: 1 26. *pl. 1.* 1889.

This fungus has long been associated with the onion mildew, and by some pathologists it is supposed that it is commonly present on diseased onions as a fungus of secondary importance. In many cases it unquestionably follows the Peronospora of this host, but in other cases it seems to be the direct cause of spots which may involve the seed stalks, or which may occur upon the older leaves and sheaths. It occurs in Europe, in the Bermudas, in the northeastern United States, and possibly throughout a wider range. It is conceivable that the fungus follows injuries of one sort or another, such as those of thrips or other insects, as well as the effects of the Peronospora, but it does not appear to be restricted to plants infested by the last-mentioned fungus. In the case of onions grown for seed it is especially injurious, since the seed stalks affected seldom mature their product. Miyabe established the genetic connection between the Macrosporium of onion and *Pleospora herbarum* (Pers.) Rab., incidentally indicating, also, that the Macrosporium agrees with the saprophytic form described by Berkeley.

XV. MACROSPORIUM: OTHER SPECIES

Occurring upon other solanaceous hosts are such species as *Macrosporium tomato* Cke. and *Macrosporium Daturæ* Fautr. Several species have been reported upon onions besides *Macrosporium Sarcinula* Berk. above discussed. Other species of Macrosporium besides the latter have also been connected with species of Pleospora.

Macrosporium nigricantium Atkinson, *Macrosporium Tabacinum* Ell. & Ev., and *Macrosporium Iridis* C. & E. are commonly reported as leaf spot or blight fungi of their respective hosts, cotton (Gossypium), Iris, and tobacco (*Nicotiana Tabacum*).

XVI. BLIGHT OF GINSENG[1]

Alternaria Panax Whetzel

Occurrence and symptoms. The so-called "blight" is the most common and destructive disease of cultivated ginseng. It occurs

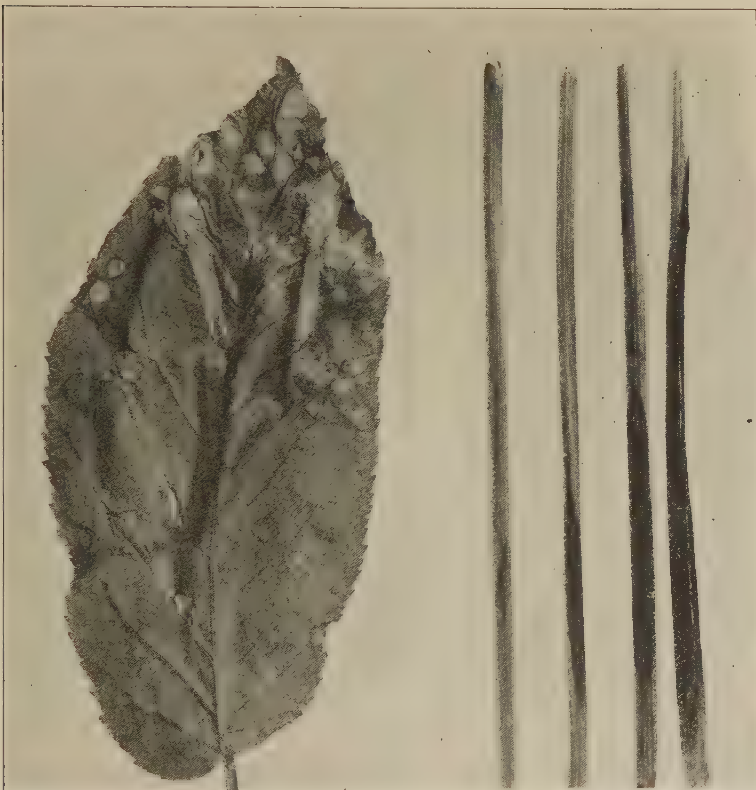


FIG. 138. BLIGHT OF GINSENG: FREQUENT FORMS OF THE DISEASE
(Photograph by H. H. Whetzel)

apparently throughout the eastern United States wherever ginseng is grown, but has not been with certainty reported west of the Mississippi. The disease is caused by *Alternaria Panax* Whetzel,

[1] This account of the blight of ginseng was kindly prepared by Professor H. H. Whetzel, Cornell University.

which, in its general characters, as regards spores (size, shape, etc.), is very much like the *Alternaria Solani* producing the early blight of potatoes. The fungus is a genuine parasite, attacking plants both young and old, and apparently under all conditions, although the disease becomes epidemic only in hot rainy weather.

The parasite attacks all of the parts of the plant above ground, but never affects the roots. During epidemic periods the disease works with great rapidity, so that the tops of plants in an entire garden may be entirely destroyed within a few days. The disease first makes its appearance as dead brown streaks or cankers on the stems of the plants near the ground. This is the primary infection in the spring, and it is probably brought about through spores that have wintered over on the mulch or débris on the soil, the stems becoming infected as they come through the ground. This first stage is usually overlooked by the grower unless it becomes severe enough to cause the breaking over of the stems, which sometimes happens. Ordinarily the first observed appearance of the disease is on the leaves, which show rather large, more or less circular, watery spots. The tissue is killed outright in those spots and later becomes dry and papery with a brown or yellowish center. Under favorable weather conditions these spots spread and coalesce, readily killing the leaves and the entire top of the plant (Figs. 138, 139), so that a badly blighted plantation looks as if it had been drenched with scalding water. If the berries set before the blight has become destructive, they may be attacked and blasted, turning brown and dropping off before they can ripen.

The fungus. The conidia or spores of the parasite are produced in great abundance on all parts of the affected plants, but particularly so on the stems and blasted berries. No perfect or winter stage has been discovered for the fungus, but the fact that the spores will germinate after remaining in the laboratory dry for three months indicates that the conidia of the fungus are probably carried over winter on the mulch or débris on the beds. It grows very readily as a saprophyte, and may pass the winter growing on the dead stems and mulch on the bed. The fungus makes its first appearance on the stems early in the spring, shortly after they are up, but the disease does not become destructive

usually before the middle or latter part of the summer; so that the tops are not often killed before the middle of July or the first of August in New York. The parasite does not pass down into the root nor does it induce rot of any kind in the roots. The general effect on the root of the plant is to reduce its growth, and probably where the blight continues year after year the root will be so weakened that it will become subject to soil rots of various kinds.

FIG. 139. BLIGHT OF GINSENG: A SEVERE ATTACK BEGINNING WHEN THE PLANTS WERE YOUNG. (Photograph by H. H. Whetzel)

Control. It has been clearly demonstrated that this disease may be controlled by thorough spraying with Bordeaux mixture. The application should begin early in the spring, as soon as the plants come through the ground, and should be kept up throughout the season every ten days or two weeks. It is particularly necessary to spray the young plants frequently when they are coming through the soil in order to protect them from the primary infection. It has been shown that ginseng is able to stand a very strong solution

of Bordeaux mixture, so that the ordinary strength may be used without causing any trouble. In the case of the early sprayings in the spring when there is apt to be cold weather, it has been found that plants will sometimes be injured by the Bordeaux. If care is taken not to apply the mixture just before a hard freeze, little trouble will result.

Alternaria Violæ Gall. & Dorsett[1] produces a leaf spot of violets in the greenhouse, particularly when the houses are not well regulated with respect to dryness or moisture of the air, heat and cold,

FIG. 140. LEAF SPOT OF BEETS; A FIELD OF SUGAR BEETS BADLY DISEASED

or when the stock is not in condition for vigorous growth. The old spots, as in the case of most violet leaf diseases, are white, although at the outset the spot is dark, and on the stem (which is sometimes affected) the darkened areas are often persistent.

Alternaria Brassicæ (Berk.) Sacc. This species is not uncommon upon cabbage and horse radish in Europe and America. It produces brown spots with concentric markings.

[1] Dorsett, P. H. Spot Disease of the Violet. Div. Veg. Phys. and Path., U. S Dept. Agl. Bullt. **23**: 1–16. *pls. 1–7.* 1900.

XVII. LEAF SPOT OF BEETS

Cercospora Beticola Sacc.

DUGGAR, B. M. Leaf Spot of the Beet. Cornell Agl. Exp. Sta. Bullt. **163**: 352–359. *figs. 56–61.* 1898.
PAMMEL, L. H. Spot Disease of Beets. Iowa Agl. Exp. Sta. Bullt. **15**: 238–243. 1891.

Habitat relations. The beet leaf spot is widely distributed. Both in Europe and America it is a fungus of common occurrence, and it is believed to be more or less prevalent wherever beets are grown even to a limited extent. The red garden beet is seldom wholly free from this fungus, although many varieties are apparently so resistant that the disease is not an important one in garden or truck work. Much damage may be done to sugar beets in any region where summer rains or heavy dews are prevalent. Spanish and Swiss chard are seldom affected to an injurious extent.

FIG. 141. LEAF SPOT OF BEETS

The leaf spots are at first very small brown flecks with reddish-purple borders. As soon as the spots attain a diameter of $\frac{1}{8}$ inch or more they become ashen gray at the center, the border remaining as before so long as the blade is green. The spots are distributed over the leaf surface (Fig. 141), and they may become so numerous as to cover a large portion of the surface, yet with no general discoloration of the blade. In time, however, the leaves blacken and dry up gradually from tip to base. As the leaves become parched and dry they stand more

FIG. 142. EFFECTS OF THE LEAF-SPOT FUNGUS: PROLONGED CROWN

nearly upright, although somewhat curled or rolled, presenting a characteristic appearance in the field.

Since the outer leaves are the first to succumb, the plant continues to develop new leaves from the bud, and the crown may thus become considerably elongated (Fig. 142), at a serious sacrifice to root development, and probably at great loss to the sugar content.

It has been stated by German observers that the leaf-spot fungus may also be found upon the bracts, peduncles, and even upon the seed pods. It is therefore thought that the fungus may be spread with the seed.

The fungus. When the leaf spots appear gray at the centers one may be sure of finding the conidiophores and conidia of the fungus in abundance. The former arise in small clusters, apparently through the stomates at first. The base of the cluster is usually a few-celled stroma. The conidiophores are flavous, and ordinarily $35-55 \times 4-5\,\mu$. The conidia are produced at the apices, and then by further growth of the conidiophores, slightly towards one side, noticeable geniculations are left, and the conidiophores are therefore flexuous. The conidia are obclavate to needle-shaped, hyaline, many-celled, $75-200 \times 3.5-4.5\,\mu$ (Fig. 143). If produced under very moist conditions,

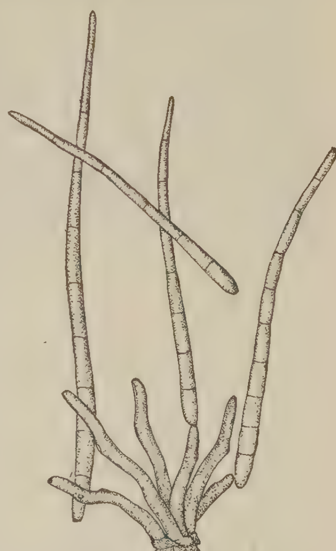


FIG. 143. *CERCOSPORA BETICOLA*: CONIDIOPHORES AND CONIDIA

as in a moist chamber, the length mentioned may be considerably exceeded. After the death of a leaf, spores may be produced over the entire surface. Spores found upon old leaves in the field five months after the beets were harvested were able to germinate.

The fresh spores germinate readily in ordinary nutrient media, and pure cultures may be obtained by the poured plate method. After a growth of a few days the colonies show up well. The submerged mycelium develops in agar as a dense olivaceous colony, the new growth lighter in appearance, forming an outer border. The aërial growth of the colonies is finally grayish green. On bean pods a copious development of mycelium occurs, but such cultures maintained for two years gave no production of conidia. Abnormal conidia may, however, be developed on this medium from other species of Cercospora in culture. Aërial hyphæ show a tendency to adhere together in slight strands or clusters, and the small branches suggest an attempt at spore production (Fig. 144, aërial). The immersed mycelium is very irregular, with many swollen cells and peculiar branches (Fig. 144). I have grown about twenty species of Cercospora in pure cultures, but in no case has any evidence or clue been obtained as to the possible connection with a perithecial form.

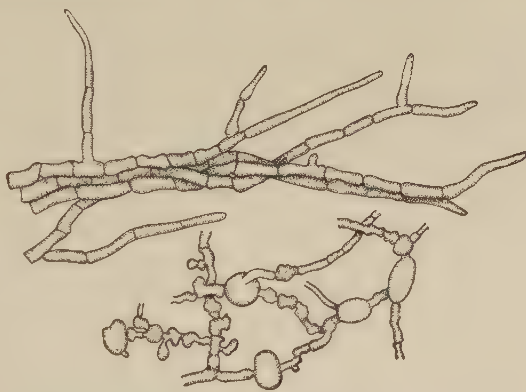


FIG. 144. MYCELIUM OF CERCOSPORA IN CULTURE: AËRIAL AND SUBMERGED FORMS

Control. Such experiments as have been made indicate that this disease can be controlled, where necessary, by Bordeaux mixture. Since the conidia may retain their vitality until late winter, it is probable that many are able to germinate after the seed are sown in the late spring; early spraying is therefore important.

XVIII. EARLY BLIGHT OF CELERY

Cercospora Apii Fr.

ATKINSON, GEO. F. Note on the Cercospora of Celery Blight. Cornell Agl. Exp. Sta. Bullt. **48**: 314–316. *fig. 5.* 1892.
DUGGAR, B. M. Early Blight of Celery. Cornell Agl. Exp. Sta. Bullt. **132**: 201–206. *figs. 48–50.* 1897.
STURGIS, W. C. On the Prevention of Leaf-Blight and Leaf-Spot of Celery. Conn. Agl. Exp. Sta. Rept. **21**: 167–171. 1897.
U. S. Dept. Agl. Rept. (1886): 117–120.

Habitat relations. *Cercospora Apii* is the cause of the chief disease of celery, beginning early in the season. It is common in the Atlantic states and well known in the Mississippi Valley. It is also a serious pest in Europe. In the early stages of the disease there is a well-defined spot with slightly raised border; but when the spots become numerous on a leaf, the latter begins to turn yellow, and subsequently the fungus develops abundantly its conidiophores in indefinite areas, thus giving the characteristic ashen or velvety spots of indiscriminate form. When a leaf becomes seriously injured it wilts and dries. The conidia are then produced in quantity over the whole surface, particularly during muggy days; thus the dead leaves increase many times the chances of further infection. This disease does not usually appear late in the season, being frequently followed by the late blight (*Septoria Petroselini* var. *Apii*) with which it has no genetic connection. This fungus also occurs on cultivated and wild parsnip (*Pastinaca sativa*) and other related plants.

FIG. 145. *CERCOSPORA APII*: ABNORMAL FRUITING IN CULTURE

The fungus. The conidiophores and conidia of this Cercospora are in no way particularly characteristic. The conidiophores and spores are variable in size, depending upon the conditions under

which produced; the former measure in extreme cases $50–150 \times 4–5\,\mu$, and the spores, $50–280 \times 4–5\,\mu$. They attain the maximum size with both high humidity and temperature. The spores retain their vitality for many months at least. Pure cultures of this fungus may be readily secured by the poured plate method, and the mycelium grows well upon bean stems and other media. In such cultures the conidiophores are most peculiar. They may attain a length of a millimeter (Fig. 145). Conidia may be produced and abscised for a time, leaving the customary geniculation; then when the hyphæ are longer, conidia-like branches arise, which remain attached, and eventually serve as true branches of permanent hyphæ. The mycelium, like that of the other Cercosporæ, is olivaceous; but the colonies show minor peculiarities distinguishing them from other species which have been thus cultivated.

Control. This fungus may be controlled by early spraying with Bordeaux mixture, 5–5–50 formula, or by repeated applications of ammoniacal copper carbonate. It is also claimed that partial shade, usually affording more equable temperature and moisture relations for the host, enable the plant to resist the fungus to a very large degree.

XIX. LEAF BLIGHT OF COTTON

Cercospora Gossypina Cke.

ATKINSON, GEO. F. Sphærella Gossypina, n. sp. the Perfect Stage of Cercospora Gossypina Cooke. Bullt. Torrey Bot. Club. **18**: 300–301. 1891.

ATKINSON, GEO. F. Cotton Leaf Blight. Ala. Agl. Exp. Sta. Bullt. **41**: 58–61. *fig. 19.* 1892.

SCRIBNER, F. L. Cotton Leaf Blight. U. S. Dept. Agl. Rept. (1887): 355–357. *pl. 4.*

This fungus produces a leaf blight of cotton. It is more common on the less vigorous or old leaves, and it is generally reported as prevalent when for any reason the vitality of the plant is lowered. The spots are at first small and red, later becoming pale and finally brown at the centers. They are generally 1–5 mm. in diameter, but sometimes confluent and extensive. Conidiophores and conidia are at first produced only in the central area of these spots, but on leaves the vitality of which is largely lost the fungus may appear over large areas. Atkinson considers this fungus a conidial stage of *Sphærella Gossypina* Atk.

XX. CERCOSPORA: OTHER SPECIES

Parallel cultures on diverse culture media of a number of species on related hosts would be of special interest. As in the case of Phyllosticta, subsequently discussed, numerous leaf spots are produced by members of this genus Cercospora. Very few cross inoculations have been made, and little is really known concerning the limitations of species. When the host plants are different, minor variations in the size, color, septation, etc., of spores and conidiophores, or in the macroscopic appearances of spots, are generally employed in distinguishing species.

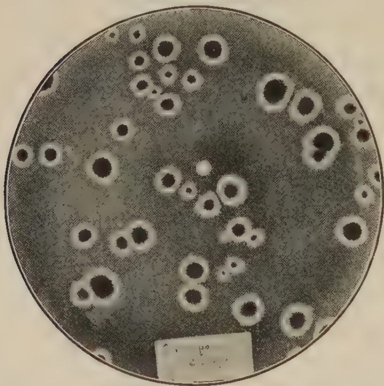


FIG. 146. *CERCOSPORA GOSSYPINA*: AN ISOLATION CULTURE

Among many other species the following upon important hosts may be mentioned.

Cercospora Viticola Sacc. This fungus produces a spot known as grape leaf blight. It has not been productive of serious damage except during unusually moist seasons. The spots are first evident on the lower surface of the leaf, and it is also upon this surface that the conidiophores are developed. Upon *Ampelopsis quinquefolia* a Cercospora is more commonly found, but apparently no comparative study of these different forms has been made.

Cercospora circumscissa Sacc. is one of the shot-hole-producing leaf fungi of the genus Prunus. It occurs on some of the native American as well as cultivated species of plums and cherries (Fig. 147) and on the nectarine and peach. It is, however, not so important from a pathological point of view upon most of these hosts as *Cylindrosporium*

FIG. 147. *CERCOSPORA CIRCUMSCISSA*: SPOTS ON ALMOND. (After Pierce)

Padi, but it is important as an almond tree disease[1] in California and elsewhere.

Cercospora Nicotianæ E. & E. The more commonly observed leaf spot or frog eye of the tobacco has been reported from many tobacco-growing regions, but does not appear to be a disease of

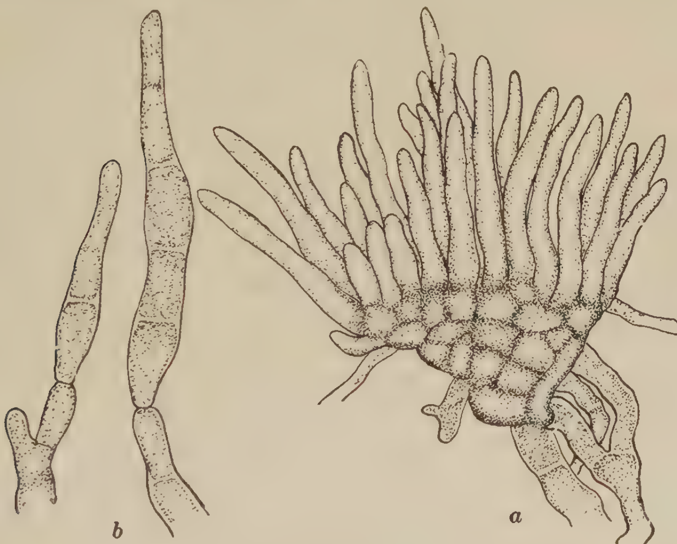


FIG. 148. *CERCOSPORA CIRCUMSCISSA*. (After Pierce)
a, tuberculate stroma; *b*, conidiophores and conidia

any great importance, and doubtless many different fungi are concerned in the production of spots more or less similar which have been reported in nonscientific literature.

Cercospora Violæ Sacc., producing white spots on leaves of the violet in the spring, is common in coldframe or garden culture.

Cercospora Diospyri Thüm. is of common occurrence in the southern states on leaves and fruit of persimmon (*Diospyros virginiana*).

Cercospora sordida Sacc. is the most important disease-producing fungus of the trumpet creeper (*Tecoma radicans*), in the United States. Pale spots are produced on the leaves, and defoliation of the host often results by midsummer.

[1] Pierce, N. B. A Disease of Almond Trees. Journ. Myc. **7**: 66–77. *pls. 11–14.* 1892.

XXI. SPONGY DRY ROT FUNGUS OF APPLE

Volutella fructi Stevens & Hall

STEVENS, F. L., and HALL, J. G. The Volutella Rot. N. C. Agl. Exp. Sta. Bullt. **196**: 41–48. 1907.

The rot of apples produced by this fungus has been reported from North Carolina in particular, although the disease has also been found upon apples from other states. The disease usually begins as a small spot which gradually increases to include the whole fruit. A characteristic of the injury is found in the coal black color of the older portions of the spot.

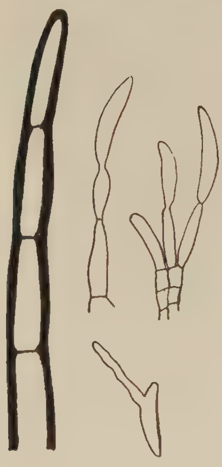


FIG. 149. *VOLUTELLA FRUCTI.* (After Stevens)

The effect upon the tissues is to produce a rather spongy dryness, and the whole affected tissue is penetrated by a much-branched, closely septate mycelium, most abundant, however, close to the cuticle; in fact, a subcuticular, hyaline stroma is formed, which in places eventually becomes palisade in arrangement. From these stromatic formations arise a mass of erect tuberculate hyphæ bearing numerous spores. Setæ are present, originating in the midst of the sporogenous hyphæ, each seta produced from the tip of a single hypha. These vary from 100 to 400 μ in length, and may be from 5 to 8 μ in diameter near the base. The conidiophores arise much higher up, and they are relatively short, simple, fertile hyphæ, each abscising many oblong-fusoid to falcate-fusoidal spores (Fig. 149).

This fungus grows readily in culture upon ordinary nutrient media, and the color of the mycelium varies greatly, being almost hyaline on some and practically black on other media. Upon the host the sporodochia occur in concentric circles, and these are commonly subcuticular at first, becoming erumpent. The conidia are continuous, hyaline to olivaceous, and about the length of the normal conidiophores. The fungus has only been found on the apple, to which it is probably confined. The disease is easily distinguished from the fruit spot.

Volutella Dianthi Atk.[1] is not uncommon on carnations in moist situations. It attacks particularly those parts more or less in contact with a damp soil. In favorable conditions the fungus may spread with great rapidity and so weaken the plant as to materially inhibit the production of flowers. It may, however, be more severe on the cutting bench, especially when sufficient ventilation or drainage is not provided.

XXII. DRY ROT OF POTATOES

Fusarium oxysporum Schl.

SMITH, ERW. F., and SWINGLE, D. B. The Dry Rot of Potatoes due to Fusarium Oxysporum. Bureau Plant Ind., U. S. Dept. Agl. Bullt. **55**: 1–64. *pls. 1–8.* 1904.

Much confusion has prevailed concerning the organisms causing some of the diseases of potatoes both in this country and in Europe. Various types of potato rot have been ascribed to a large number of different organisms, oftentimes upon insufficient proof, or sometimes merely from a single observation indicating the association therewith of a particular fungus.

It is very probable that many of the diseases described under the name of dry rot, end rot, bundle blighting, etc., are due to the fungus here discussed. Smith and Swingle have, by careful cultural and inoculation experiments, demonstrated the causal connection of a Fusarium with these types of disease, and they have taken as the name of the species here discussed the earliest described species of Fusarium associated with such diseases, namely, the one given above, and they would regard as probably synonymous with this species half a dozen or more names subsequently applied to fungi described as producing more or less similar types of disease in the potato.

Symptoms. The effect of this fungus upon the host is primarily to produce a wilt, although previous to the wilting the affected plants have a tendency to lie prostrate on account of the gradual destruction of the root system by the fungus. The fungus apparently gains entrance through the roots, and from these parts

[1] Halsted, B. D. The Carnation Anthracnose. N. J. Agl. Exp. Sta. Rept. **14**: 385–386. 1893.

spreads to the stem and leaves. Entrance to the tubers is gained, therefore, as a rule, through the stems upon which they are borne. The vascular system of the host plant is discolored, although frequently the tubers are not seriously injured externally until after they are gathered. In storage, however, the fungus progresses rapidly, blackening the vascular ring. At this stage the disease is only made apparent in the tubers by cutting them crosswise; still it may be so serious as to render them unavailable for table purposes. Later on there may be considerable drying of the tubers, or soft rots due to secondary organisms may ensue.

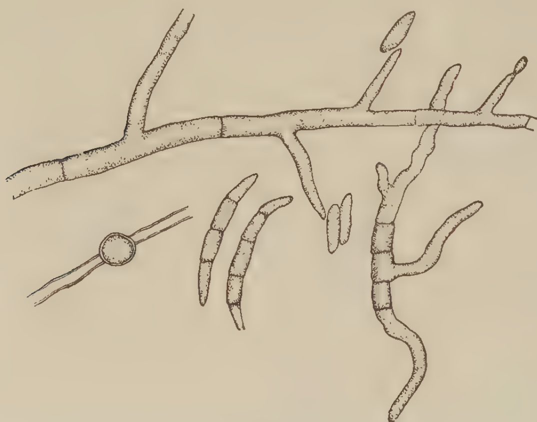


FIG. 150. *Fusarium oxysporum:* MYCELIUM, CONIDIA, AND CHLAMYDOSPORE

The fungus. The mycelium produces microconidia and macroconidia (Fig. 150) abundantly in artificial cultures, also some chlamydospores. On boiled potatoes small greenish sclerotia are developed, but no ascogenous stage has thus far been connected with this species.

Control. This fungus lives apparently for a considerable time in the soil, and a rotation of crops is essential whenever it becomes of serious importance. Again, the use of pure seed only should be allowed. If necessary, inspect by cutting a large number of the tubers which are to be used for this purpose. All diseased and discarded tubers should be burned and not returned to the land. Seed tubers which may have come in contact with conidia should be treated as for potato scab.

The sleepy disease of tomatoes which has been attributed to *Fusarium Lycopersici* Sacc. may also be produced by the fungus above described, although this point has not been demonstrated experimentally.

XXIII. FLAX WILT

Fusarium Lini Bolley

Bolley, H. L. Flax Wilt and Flax Sick Soil. N. D. Agl. Exp. Sta. Bullt. **50**: 27–60.

This important flax disease, which is reported as particularly destructive in North Dakota, seems to be characterized by symptoms similar to many other diseases caused by species of Fusarium. Affected plants may be killed in the seedling stage, or they may wilt and die at any time during the growing period.

The fungus has been found to be ordinarily very abundant in soils in which flax has been grown several successive years, and it is considered to be the chief cause of the failure of flax upon land where flax has previously been grown. In fact, Bolley points to this fungus as the cause of flax-sick soil. It would seem to be doubtful, however, if the action of this fungus would explain all the peculiar relations of flax to the soil upon which it has been grown. The fungus produces an abundance of conidia which are typically somewhat curved, 4-celled, and prompt to germinate. No perfect stage of this organism has been found. It is believed that the old straw, stubble, etc., of diseased stalks harbor the fungus, and that since the fungus is in nature, perhaps, more particularly a saprophyte, there is ordinarily abundant opportunity for it to be carried over from one year to the next.

Fig. 151. China Asters dwarfed and killed by Fusarium

Control. Control consists of seed treatment; yet in this connection it should be said that the seed of flax are very readily injured by treatment even with water, and therefore much caution is needed to prevent injury to the seed. It is advised to sprinkle the seed with a formalin solution, using formalin at the rate of

about 2 ounces to each 5 gallons of water. The treatment should be given while the seed are spread out on a floor or canvas, and as the seed are sprinkled the grain must be handled continuously with a shovel or rake, so that they may be moistened, but not wet, throughout. Subsequently, they should be handled until dry. Preceding this treatment, moreover, the seed should be thoroughly cleaned in the fanning mill. All straw, chaff, and other refuse from the previous crop should be taken from the land, as far as practicable.

XXIV. FUSARIUM: OTHER SPECIES

It is apparent that the old view, which held species of the genus Fusarium to be largely saprophytic, must be considerably modified. It is a genus which will well reward the student who may devote himself to it.

FIG. 152. CHINA ASTER AFFECTED BY FUSARIUM

Reed[1] has recently described a disease of the ginseng caused by a species of Fusarium. The cultural characters of the organism isolated led him to believe that it is at least the same species as that producing the wilt of cotton and other plants, and although the ascigerous stage was not found, he referred it to *Neocosmospora vasinfecta* (Atk.) Erw. Smith.

A destructive stem blight (Figs. 151, 152) of the China aster, *Callistephus hortensis* Cass., has been attributed to a Fusarium, but a complete

[1] Reed, H. S. Diseases of the Cultivated Ginseng, Missouri Agl. Exp. Sta. Bullt. **69**: 43–65. *figs. 1–8.* 1905.

study of the disease does not appear to have been reported.

The carnation stem wilt,[1,2] or rosette, is occasionally important both in the greenhouse and garden. As in the case of the cotton wilt and other similar diseases, the fungus seems to gain entrance through the root system, and its path of attack is mainly the tracheal tissues. Sterilization of the soil seems to be the only effective means of prevention.

FIG. 153. FUSARIUM ON CARNATION: ROSETTE EFFECT
(Photograph by Geo. F. Atkinson)

XXV. ROOT ROT OF THE VINE

Dematophora necatrix Hartig

HARTIG, R. Rhizomorpha (Dematophora) necatrix n. sp. Unters. a. dem forstbot. Institut zu München. **3**: 94–141. *pls. 6, 7.* 1883.

VIALA, P. Monographie du Pourridié des Vignes et des arbres fruitiers. 118 pp. *7 pls.* 1892.

VIALA, P. Pourridié. Maladies de la Vigne. 248–329. *figs. 74–125.* 1893.

There is said to exist throughout a large part of Europe and the United States a root disease of the grapevine due to the fungus given above. In recent years investigations in the United States have apparently failed to develop any special disease to which the characteristics usually associated with Dematophora would apply. Moreover, the studies in Europe, unfortunately, develop much conflicting evidence. It would, therefore, seem necessary before forming any final judgment in this matter to await further critical study. It is quite possible that several independent diseases are here confused. The fungus is generally described as having several types of mycelium. It is stated that

[1] Atkinson, Geo. F. Carnation Diseases. Amer. Florist **8**: 720–728. 1893.

[2] Sturgis, W. C. Preliminary Investigations on a Disease of Carnation. Conn. (New Haven) Agl. Exp. Sta. Rept. **21**: 175–181. 1897.

directly associated with the roots, the mycelium may be at first almost white and flocculent, later becoming brownish-red. A rhizomorphic stage is also developed, which is clearly distinguishable from that of *Agaricus melleus*. This may be in contact with the roots, often beneath the bark, but it also provides for the spread of the fungus through the soil. It may give rise to a filamentous mycelium in the soil. According to Hartig tuberculate sclerotia are often produced from the strand beneath the bark or from the general mycelium upon the dead vines. From the sclerotia as well as from any superficial mycelium there may arise clusters of hyphæ (conidiophores) bearing minute, simple, hyaline conidia. Pycnidial and perithecial stages have been described. Hartig was convinced that he had clearly established the parasitism of Dematophora and that it might be considered a fungus of much practical significance, not only with respect to viticulture, but also important in connection with the fruit interests generally, for the fungus is reported as of serious consequence to fruit orchards throughout southern Europe. Diverse opinions prevail with respect to a perfect stage of this organism.

XXVI. ANTHRACNOSE OF BEAN

Colletotrichum Lindemuthianum (Sacc. & Magn.) Scribner

Beach, S. A. Bean Anthracnose and its Treatment. N. Y. (Geneva) Agl. Exp. Sta. Rept. **11**: 531–552. *figs. 1–7.* 1892.

Fulton, H. R. Bean Diseases. Anthracnose or Pod Spot. La. Agl. Exp. Sta. Bullt. **101**: 9–13. 1908.

Whetzel, H. H. Some Diseases of Beans. Cornell Univ. Agl. Exp. Sta. Bullt. **239**: 198–214. *figs. 99–115.* 1906.

Whetzel, H. H. Bean Anthracnose. Cornell Univ. Agl. Exp. Sta. Bullt. **255**: 431–447. *figs. 217–222.* 1908.

Distribution and host relations. The bean anthracnose or pod spot ranks with the blight in importance. It is widely distributed throughout the limits of bean culture, and it occurs both upon field and garden varieties. There are probably some differences in the resistance of the various varieties to the attacks of the fungus, but there is as yet no experimental evidence to show that immune varieties exist. It is probable that many of the so-called "rust-proof" sorts indicate merely that the seed were selected, through a generation or two, from fields which showed

no anthracnose. In general, it should not be taken to indicate that such seed will remain free from the disease.

The fungus attacks pods, stems, and leaves, but the most conspicuous injuries are the spots upon the pods (Fig. 154). These appear first as small, brownish, or purplish discolorations, and as the fungus spreads radially the central portion becomes dark and sunken. Neighboring spots may also coalesce, so that irregular sunken patches may result. The conidia in quantity have a pinkish tint, and the ulcerated areas develop the spores so profusely that this color becomes pronounced under favorable conditions. The fungus may appear upon the cotyledons or young hypocotyls of the seedlings, and this is usually indicative of badly affected seed.

FIG. 154. ANTHRACNOSE OF BEANS (Photograph by H. H. Whetzel)

The fungus. The mycelium penetrates the affected parts to a considerable extent. The bean seeds beneath the lesions on the pods are commonly spotted or slightly discolored, and a careful examination would show that the fungous hyphæ are also present in those parts. Distribution of the fungus another year is insured through such infected seed.

Beneath the cuticle or epidermis of the older spots a stromatic mass of hyaline hyphæ is developed, and from this arise numerous short conidiophores bearing the irregularly elliptical conidia (Fig. 156). Near the margins of these spore pustules, or acervuli,

a few dark colored setæ are developed.[1] The conidia measure $15-19 \times 3.5-5.5 \mu$. They germinate readily and usually become septate during the process. Each conidium is inclosed by a gelatinous envelope which when dry glues it to other spores or to any object upon which it falls; when moist, however, the spores are readily separated and distributed.

FIG. 155. COLLETOTRICHUM FROM BEAN: AN ISOLATION CULTURE. (Photograph by Geo. F. Atkinson)

Control. Very diverse methods of controlling this important disease have been suggested. Seed selection is important, but it is not sufficient to select seed which do not *appear* to be infected, for many minute infections will be overlooked. It is desirable, therefore, to select healthy seed from healthy pods, preferably from a field which shows the disease slightly or not at all. Whetzel's experiments thus far seem to indicate that this latter type of selection yields most satisfactory results.

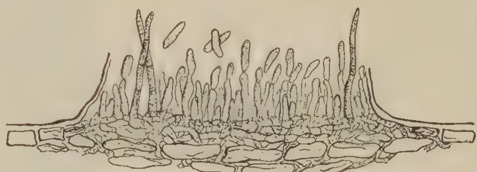


FIG. 156. *COLLETOTRICHUM LINDEMUTHIANUM*

Spraying with Bordeaux mixture, 5–5–50 formula, is to be advised when the disease appears early and when the facilities are at hand to make a thorough application of the spray. Burning infected material is necessary; moreover, rotation of crops is important.

[1] The setæ in this case are not commonly a conspicuous part of the acervulus, and in a cursory examination of the fungus they may be sometimes overlooked. In fact, this fungus was at first placed in the genus Glœosporium. It is possible that climatic conditions or the texture of the host may be important in determining the relative number of setæ.

XXVII. ANTHRACNOSE OF COTTON

Colletotrichum Gossypii Southworth

Atkinson, G. F. Anthracnose of Cotton. Journ. Mycology **6**: 173–178. *pls. 17–18.* 1891.
Atkinson, G. F. Some Diseases of Cotton. Ala. Agl. Exp. Sta. Bullt. **41**: 40–49. *figs. 9–13.* 1892.
Southworth, E. A. Anthracnose of Cotton. Journ. Mycology **6**: 100–105. *pl. 4. figs. 1–8.* 1890.

Habitat relations. Anthracnose of cotton exists as a malady of some importance upon rich land in some of the cotton-growing, particularly the Gulf, states. It would seem that the fungus is widely distributed, but serious injury is doubtless dependent upon local conditions.

Fig. 157. Anthracnose of Cotton. (After Geo. F. Atkinson)

The lesions of this fungus are more important when bolls and seedlings are infested, but injuries to stems and leaves are not uncommon. Upon the bolls the minute reddish spot at first evident about an infection center rapidly increases in size, the injured area, marked by a reddish border, becoming black and slightly depressed. Many spots may become confluent, so that very irregular outlines may result. As the development

of conidia proceeds, in the older areas the spots vary from gray to bright pink. Through such injuries the boll is usually seriously damaged and may never open. Moreover, through the boll injuries the fungus may probably penetrate the seed and thus be carried over and distributed the following season. Seedlings may be affected either upon cotyledons or stem, especially upon employing diseased seed, and at this stage the plantlet is readily wilted as a result.

Upon stems of the adult plant the Colletotrichum seems to be largely a wound parasite, although in continued moist weather direct injury may be induced. Upon mature leaves it is said to take the form of a scald, or frost effect, and it may also accompany other leaf diseases.

Characters of the fungus. From a loose stroma within the tissues conidiophores of two types break through the epidermis and produce conidia abundantly. Small hyaline conidiophores, usually less than twice the length of the conidia, are more numerous, and they arise in a compact mass, each abscising one conidium after another. The spores are (see Southworth) $4.5-7 \times 15-20\mu$, oblong, the diameter of the middle portion sometimes less than at the ends, usually pointed at the base, and vacuoles may be present. The other form of the conidiophores, termed setæ, arise later from dark colored cells of the stroma. These setæ, which usually appear in clusters of 5 to 10, are of a dark olive color, 100 to 250μ long, tapering and septate. They bear ovate, basally pointed spores. The mass of conidiophores and spores produced in this manner constitute the acervuli. In this form an acervulus may be from 100 to 150μ in diameter.

The spores germinate readily in almost any nutrient media, usually becoming once or twice septate during germination. The mycelium, which grows vigorously in culture, is hyaline, flexuous, and abundantly septate. Short conidiophores are promptly produced. The conidia are borne singly, but by virtue of a slightly gelatinous envelope they may adhere in a crown about the tip of the conidiophore. Appressoria are also produced by the mycelium, and these give rise to other similar structures, to an ordinary hypha, or to a conidiophore. Such dark cells are also developed from a germ tube when germination proceeds in water. The setæ have also been produced in culture.

Control. Adequate methods of control have not been developed. It is important, however, to select varieties which permit the access of light to the bolls. Seed selection from healthy bolls may prove of value.

XXVIII. WITHER-TIP AND SPOT OF CITRUS FRUITS

Colletotrichum Glœosporioides Penz.

Rolfs, P. H. Wither-Tip and Other Diseases of Citrus Trees and Fruits. Bureau Plant Ind., U. S. Dept. Agl. Bullt. **52**: 1–20. *pls. 1–6.* 1904.

Host relations. In practically all parts of the world in which the orange and other citrus fruits are cultivated this fungus is more or less common. The diseases or injuries produced by it are variously known as wither-tip, leaf spot, anthracnose, canker, and lemon spot, depending upon the effects upon the host. The fungus is a far more active parasite in humid regions, and in Florida, particularly, the disease appears to be growing in importance from year to year. In 1891 it was casually noted by Underwood, and since that time it has rapidly come into prominence as a destructive agent to the citrus industries.

On orange. The wither-tip effect is particularly characteristic of orange trees. It may be found upon trees of all ages, affecting and killing back the tips of the branches. On large trees this necessarily prevents the setting of a heavy crop of fruit. The varieties of the orange seem to be about equally affected. The disease is easily distinguished from dieback (a disease not associated with a specific organism) by unmistakable characters, especially by the ashen color of the twigs where dieback effects are brown; by the line or ring separating injured from healthy tissue, which is absent in the other disease; by the absence of any resinous deposit; and by the frost-like killing of twigs, where in dieback twisted branches and the development of twigs with brown-stained bark are common.

On lemon. Upon the lemon it causes not only a wither-tip, but also a very definite leaf spot, and from the diseased areas of the leaf the fungus may extend into the twigs, thus resulting in the wither-tip, the more acute form of the trouble. The mature fruit may also be affected in the form of a fruit spot. It would appear

that penetration of the fruit is probably gained through some injury or abrasion. A dark spot is invariably produced, but ordinarily no rot results. The spot on the fruit, however, may not manifest itself before shipment to market, and therefore the quality of a large shipment may be materially affected.

On the lime. Upon the lime practically all forms of the disease are to be seen, and it is the host which is most seriously affected. It occurs as wither-tip, and the infection is through the terminal bud. It may also occur as a fruit canker, and more particularly as an "anthracnose" on the young growing shoots.

The fungus. According to Rolfs, the acervuli are produced in many of the diseased areas, whether of leaf, twig, or fruit. The spores are produced on short conidiophores, among which are interspersed, especially at the margin of the acervuli, certain fuliginous setæ, from 60 to 160 μ long, and once or twice septate. There are, however, smaller setæ throughout; yet on tender twigs few setæ may appear. The conidia develop from short conidiophores 3 to 18 μ, arising from a more or less definite stroma.

Control. It has been found that the disease may be held in check by proper spraying, especially with Bordeaux mixture. The time of spraying, however, depends upon the form of the disease, wither-tip and leaf spot being preferably pruned out and the trees subsequently sprayed. The fruit of the lemon will not, however, permit of the use of Bordeaux, and the lemon spot may, therefore, be best controlled by sprinkling the fruit with ammoniacal solution of copper carbonate before picking.

XXIX. ANTHRACNOSE OF CLOVER AND ALFALFA

Colletotrichum Trifolii Bain

BAIN, S. M., and ESSARY, S. H. Selection for Disease-Resistant Clover. Tenn. Agl. Exp. Sta. Bullt. **75** (Vol. **19**, No. 1): 1–10. *figs. 1–5.* 1906.

BAIN, S. M., and ESSARY, S. H. A New Anthracnose of Alfalfa and Red Clover. Journ. Mycology **12**: 192, 193. 1908.

An investigation of the causes of failure in red clover growing in Tennessee has resulted in the discovery of an anthracnose as the chief agent. This fungus attacks also alfalfa, but alsike clover is practically immune. The fungus has been reported also from West Virginia and Arkansas.

The fungus produces black spots on stems and petioles, very rarely on the leaves. It is stated that the plants seem to suffer the greatest injury, first, when the seedlings encounter prolonged dry weather; and again, during the ripening of the seed, — when the effects are more severe on the stems just above the surface of the ground. The conidia are hyaline, generally straight and rounded, $11–13 \times 3–4 \mu$. The setæ are continuous or 1-septate, fuliginous, apex pale, $39–62 \times 4–7 \mu$, often sinuous or nodulose. It is improbable that any cultural methods would be effective in preventing the spread of this disease. Selection of seed from apparently resistant plants have yielded offspring which likewise developed the disease to less extent. It remains, however, to be seen if this may not be due in part to clean seed selection.

XXX. ANTHRACNOSE OF SNAPDRAGON

Colletotrichum Antirrhini Stewart

STEWART, F. C. An Anthracnose and a Stem Rot of the Cultivated Snapdragon. N. Y. Agl. Exp. Sta. **179**: 105–109. 1900.

The above fungus is, according to Stewart, the most serious disease of the snapdragon (*Antirrhinum majus*), as cultivated in greenhouses in the United States. It is also destructive in the garden. In greenhouses the greatest injury occurs generally in the spring and fall, and in the open during late summer. It attacks both stems and leaves at practically any stage of growth.

On the leaves circular dead spots are produced, and on the stems elliptical sunken areas 3–10 mm. in length. The spots on the stems frequently become confluent, and girdling may sometimes result.

Small dark stromata are produced in the centers of these spots, each under favorable conditions becoming an acervulus by producing short conidiophores bearing straight or slightly curved conidia, $16–21 \times 4 \mu$, and also several dark, tapering setæ, $50–100 \mu$ long.

Cuttings should be made from healthy plants only, and overhead watering avoided when possible. If it is necessary to spray young plants, Bordeaux mixture is effective; but a fungicide which does not discolor the foliage should be substituted if further treatments are required.

XXXI. COLLETOTRICHUM: OTHER SPECIES

Among numerous other species of economic importance the following may be mentioned.

Colletotrichum Lagenarium (Pass.) Ell. & Hals. The anthracnose of cucumbers, squash, watermelons, etc., is a disease of both leaves and fruit. On the former brown spots are produced, causing early maturity of the leaf; but the more serious form of the trouble is on the fruit, where water-soaked, finally sunken spots are developed. In these spots appear acervuli producing numerous conidia adhering in the form of viscid masses pink in color. A mold-like growth of superficial hyphæ may also appear in moist weather. In time the whole fruit may rot, saprophytic organisms assisting.

Colletotrichum falcatum Sacc. is believed to be the chief cause of the red rot[1] of sugar cane (*Saccharum officinarum*) in the East Indies and in the Hawaiian Islands.

Colletotrichum Phomoides (Sacc.) Chester[2] is the cause of a disease of the tomato fruit characterized by discolored, sunken spots. Under moist conditions these spread quickly, become confluent, and there is produced a general decay. At first distinct acervuli are produced, but with the softening of the tissues a continuous stratum of conidiophores and setæ may arise. This is regarded as wholly distinct from a species on peppers, *Colletotrichum nigrum* Ell. & Halsted, described a few years earlier.

XXXII. GLŒOSPORIUM

The genus Glœosporium has been discussed in part, inasmuch as several species of this form genus have been definitely connected with several genera of Ascomycetes already treated. Specific names have been assigned to forms of this genus on several hundred host plants. Many of these are fungi of great economic importance. They are parasites whose attacks frequently amount to epidemics. Nevertheless, these fungi are grown in artificial cultures, as a rule, with the greatest readiness. Moreover,

[1] Lewton-Brain, L. Red Rot of the Sugar Cane Stem. Exp. Sta. of the Hawaiian Sugar Planters Assoc. Bullt. **8**: 1–44. *figs. 1–13.* 1908.

[2] Chester, F. D. Diseases of the Tomato and Their Treatment. Del. Agl. Exp. Sta. Rep. **4**: 60–62. *figs. 8–10.* 1891.

such cross-inoculation experiments as have been made indicate that many species, at least, are not closely restricted as to hosts, and one form might be the cause of disease in a variety of plants. It has seemed to be a group which would well reward comparative study in artificial culture, and advantage has been taken of this by Stoneman,[1] Edgerton,[1] and others. With particular reference to species of one type, those which may represent stages of the pyrenomycetous genus Glomerella, Edgerton says in part:

There are many closely related forms and species and all are variable. They vary under artificial cultivation and probably under natural conditions. Many are similar enough to be considered the same species, but evidence sufficient to warrant bringing together the related forms as one species is generally lacking.

In the determination of a species too much dependence cannot be placed upon cultural characters alone. These characters are useful, but are not sufficiently constant to justify exclusive use.

Thus far species of Glœosporium seem to have been definitely connected with three genera of Ascomycetes, as follows: Pseudopeziza, Glomerella, and Gnomonia, the imperfect stages of which were respectively known as *Glœosporium Ribis* (Lib.) Mont. & Desm., *Glœosporium fructigenum* Berk., and *Glœosporium nervisequum* Sacc. The imperfect form is invariably the important stage from the phytopathological point of view. The effects upon the hosts are in every way comparable to those resulting from the attacks of various species placed in the closely related genus Colletotrichum previously described. In fact, some species of Glœosporium occasionally produce a small number of setæ under special conditions. Upon the

Fig. 158. Glœosporium on Leaves of Norway Maple

[1] See Bitter Rot of the Apple, p. 271.

twig cankers the glœosporial stage of the apple bitter rot fungus may produce these. Moreover, in artificial cultures species of Colletotrichum have also yielded ascigerous stages referable to the genus Glomerella.[1] On the other hand there is a fairly close relationship between extreme forms of Colletotrichum and Volutella.

In members of both Colletotrichum and Glœosporium it has long been known that when conidia germinate in a drop of water on a glass slide, or under certain other conditions, structures resembling secondary or resting spores may be formed. Hasselbring[2] has made a special study of these and concludes:

> The spore-like organs formed by the germ tubes of the anthracnoses are adhesion organs, by means of which the fungus is attached to the surface of its host during the early stages of infection. They are not suited for dissemination and therefore are not to be regarded as spores. The adhesion discs are formed as a result of stimuli from mechanical contact acting on the germ tubes. When growing in nutrient media the germ tubes lose their power of reacting to contact stimuli by the formation of appressoria. Under natural conditions the appressoria are formed as soon as the germ tube emerges from the spore.

XXXIII. ANTHRACNOSE OF GRAPE

Glœosporium ampelophagum Sacc.

SCRIBNER, F. L. Report on Fungous Diseases of the Grape Vine. Anthracnose. Division of Botany, U. S. Department of Agriculture, Bullt. **11**: 34–38. *pl. 6.* 1886.

VIALA, T. Les Maladies de la Vigne. Anthracnose. pp. 204–247. *pls. 5–6. figs. 60–73.* 1893.

The anthracnose or bird's-eye disease of the grape is a striking disease now well distributed throughout Europe and America. It was not observed extensively in the United States until about 1885, and there are few localities in which it has become a malady so constant in succeeding seasons as the black rot or the downy mildew. It is, however, a disease which may cause great injury when it becomes epidemic, particularly in view of the fact that it is not so readily treated.

The disease occurs upon berries, shoots, and leaves, but is far more common upon shoots and berries. Upon the latter the well-known

[1] Edgerton. Bot. Gaz. **46**, *l. c.*

[2] Hasselbring, H. H. The Appressoria of the Anthracnoses. Bot. Gaz. **42**: 135–142. *figs. 1–7.* 1906.

bird's-eye spots, or effects, are produced. At first ashen-brown spots appear, and as these enlarge in a more or less regular manner the central portion becomes sunken, and between the paler central portion and the brown outer border a band of red or red-purple is apparent. The unaffected portion of the berry remains perfectly green, but the spot may at times embrace eventually the entire berry. When the shoots are affected the spots are similar to those on the fruit except that they elongate in the direction of the axis, becoming prominently sunken, pale at the center, and

FIG. 159. *Glœosporium ampelophagum:* ANTHRACNOSE OF GRAPE

always less highly colored. The young leaves are also affected with spots with pale centers and brown-red borders.

The acervuli of the fungus appear more commonly upon berries and twigs. The fungus resembles very closely, in general, other species of Glœosporium. A large number of minute conidiophores are produced, each of which may originate many conidia. The latter may be elliptical, ovate, oblong, or even slightly constricted at the middle portion. These are usually $5–6 \times 2.5–3.5\,\mu$. By some it has been claimed that the anthracnose of the grape is the same fungus as that producing the bitter rot of the apple, but this is probably incorrect. It is quite probable that a ripe rot of the grape

may be induced by *Glomerella rufomaculans*, the fungus of bitter rot; but the typical anthracnose has not been produced by inoculations with the apple fungus. Moreover, the species here discussed seems to be more closely restricted in its conditions of growth. Upon artificial media it grows slowly and with less vigor than is commonly the case with many species of anthracnose.

Control. Experiments concerned with the prevention of this disease indicate that the usual spraying operations as recommended for the black rot are not necessarily effective for the anthracnose. Nevertheless, it is doubtful, under ordinary circumstances, if other precautions need be taken. When the fungus appears in an epidemic form it will be necessary not only to spray repeatedly with Bordeaux, but also to prune out and burn as promptly as possible the diseased canes and fruit bunches.

XXXIV. ANTHRACNOSE OF RASPBERRY AND BLACKBERRY

Glœosporium Venetum Speg.

Detmers, Freda. Anthracnose of Raspberry and Blackberry. Ohio Agl. Exp. Sta. Bullt. **4** (No. 6): 124–126. *pls. 3–4.* 1891.

Paddock, W. Anthracnose of the Black Raspberry. N. Y. Agl. Exp. Sta. Bullt. **124**: 261–274. 1897.

Scribner, F. L. Anthracnose of the Raspberry and Blackberry. U. S. Dept. Agl. Rept. (1887): 357–367. *pl. 5.*

This fungus produces the well-known anthracnose of raspberries and blackberries (*Rubus* spp.), characterized by injuries of the canes. Raspberries are commonly more seriously affected. Small purplish spots appear at first, later the center becomes gray and sunken, giving somewhat the bird's-eye effect. Petioles and veins of leaves may also be affected, and the injuries are severe. Minute spots sometimes appear on the blade of the leaf. The acervuli appear frequently in the older spots. Control measures have not been as effective as may be possible. The pruning out and destruction of diseased canes is essential, and thorough spraying with Bordeaux may be practiced during the early part of the season. Spraying alone is not ordinarily sufficient for the proper control of this disease. Healthy plants only should be set, and a short rotation practiced.

XXXV. GLŒOSPORIUM: OTHER SPECIES

In addition to the preceding, and to the various fungi already discussed which have glœosporial stages, the following inducing diseases of some shrubs or trees may be briefly cited.

Glœosporium Tiliæ Oudem.[1] occurs throughout a large portion of northern Europe as an important parasite of the linden (*Tilia Ulmifolia*). In late spring the clear, circular spots appear upon the leaves, generally irregularly distributed and becoming with age yellowish brown and separated from the healthy tissue by a darker brown line. The spots may also occur on the leafstalks and on the twigs as small, sunken areas. Severe attacks upon the leafstalks cause a premature defoliation. The acervuli appear most abundantly upon the upper surfaces of the spots. The conidia are generally ovate, elliptical or falcate, and measure 10–18 × 4–6 μ.

Glœosporium Juglandis (Lib.) Mont. is a cause of a serious leaf blight of the butternut (*Juglans cinerea*). The fungus has been found practically throughout the range of the butternut. The effects of the fungus have often been severe in the northeastern states, where almost complete defoliation of some trees has been noted as early as the latter part of July in New York, and early August in Massachusetts. Quite generally the fungus causes a defoliation which is earlier than the normal. The leaves affected are covered with irregular brown spots, which rapidly induce ripening, and defoliation results.

Glœosporium cingulatum Atkinson[2] is an anthracnose of the privet (*Ligustrum vulgare*). The fungus attacks the young twigs, producing at first small dark, sunken spots, but eventually girdling and killing the twigs. It is considered distinct from *Glœosporium Ligustrinum* Sacc.

Glœosporium læticolor Berk., while widely distributed, occurring particularly upon peaches and apricots, has apparently never been reported of serious importance in the orchard.

Glœosporium apocryptum E. & E. on leaves and young twigs of the Norway maple is an important disease in the nursery.

[1] Laubert, R. Eine wichtige Glœosporium Krankheit der Linden Zeitsch. f. Pflanzenkr. **14**: 257–262. *pl. 6.* 1904.

[2] Atkinson, Geo. F. A New Anthracnose of the Privet. Cornell Agl. Exp. Sta Bullt. **49**: 306–314. *figs. 1–4.* 1892.

XXXVI. MARSONIA

Marsonia Populi (Lib.) Sacc.[1] is a common leaf spot or anthracnose of many species of poplar (Populus) in Europe and America. It is more frequently seen upon the white poplar (*Populus alba*). It is often a destructive fungus in the nursery. It may also appear as a twig blight. The young leaves may be killed and the fungus may even extend to the main shoot and branches, or it may occur upon the twigs in isolated black spots. When somewhat older, nursery stock may show black spots at the older nodes, indicating, apparently, infection through the leaves.

Marsonia ochroleuca B. & C., causing a leaf spot of chestnut, is a fungus which, while far less dangerous to the general growth of the chestnut tree than the canker, is far more widely distributed, and seems to occur wherever the chestnut is known. It is frequently injurious to a noticeable extent. Klebahn[2] has demonstrated a connection between one species of Marsonia, *Marsonia Juglandis*, and *Gnomonia leptostyla*.

XXXVII. PEACH BLIGHT

Coryneum Beijerinckii Oudem.

SMITH, R. E. California Peach Blight. Cal. Agl. Exp. Sta. Bullt. **191**: 73–100. *figs. 1–16.* 1906.

Habitat relations. It is somewhat difficult to determine the extent of injury caused by this fungus, since references to a disease produced by this or related fungi have not always been clearly differentiated from other peach diseases. In recent years, however, this disease has been studied in California, where it has been unusually prevalent, causing great destruction during 1905–1906. The organism had become gradually very abundant, and the seasons were favorable to its continued spread. In general, the effect of the fungus is to kill the buds on the fruiting wood, to produce spots on the green twigs, to retard the development of the leaves, and to cause dropping of the fruit. Accompanying the activity of this fungus is a notable gumming of the twigs from the dead spots, this being particularly abundant during moist conditions. It will

[1] Halsted, B. D. Poplar Blight in the Nursery. N. J. Agl. Exp. Sta. Rept. **15**: 349–396. 1894.

[2] Klebahn, H. Centrbl. f. Bakt. u. Infekskr. **15** (2 Abt.): 336. 1905.

be seen, therefore, that many symptoms of the disease as described in California are more or less identical with *Clasterosporium carpophilum* (Lév.) Aderh., as described by McAlpine[1] in Australia. It also occurs in Algeria.[2] According to Smith, the fungus could not be mistaken for a simple hyphomycete, as shown by the aggregate conidiophore production (Fig. 160). The conidial stage of the fungus is produced both on leaves and shoots, the pustules appearing at the center of the spots. They are, however, not readily observed, since the spots on young shoots are often sterile and those upon the leaves may fall out before the production of spores. Perhaps the most unfortunate phase of this disease is killing of winter buds, which of course greatly destroys the vitality with respect to fruit production the following season. It is quite probable that this fungus is the same as *Helminthosporium carpophilum* (Lév.), and this is also the view of McAlpine.

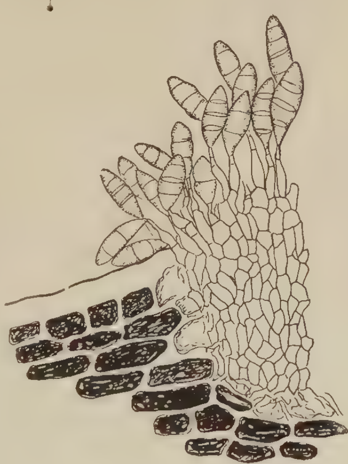


FIG. 160. *CORYNEUM BEIJERINCKII* (After R. E. Smith)

Control. In controlling this disease, it has become evident that winter spraying is essential. The disease is reported to make its appearance early in January in California, and generally somewhat prior to the activity of the winter buds. The spraying which may be given for prevention of leaf curl is ordinarily too late for the best results upon this blight fungus. It is recommended, therefore, that an additional spraying in California be given in November or December to assist in controlling this blight organism. If a single spraying only can be given, it is perhaps best to give it in December, but later than early January under California conditions is ineffective.

[1] McAlpine, D. Fungous Diseases of the Stone Fruits in Australia, and Their Treatment. 1902.

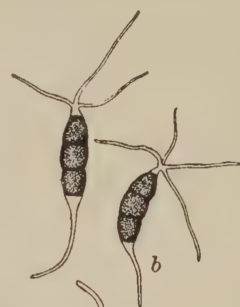
[2] Trabut, L. Le Coryneum. Maladies des arbres à noyaux. Bullt. agr. de l'Algérie et de la Tunisie **10**: 1904.

XXXVIII. LEAF BLIGHT OF CRANBERRY

Pestalozzia Guepini Desm. var. Vaccinii Shear

Shear, C. L. Cranberry Diseases. Bureau Plant Ind. U. S. Dept. Agl. Bullt. **110**: 38–39. 1907.

This fungus is often found upon the cranberry, but it is doubtless of minor importance as affecting the production of berries. It occurs upon fruit and leaves. The appearance of affected berries is not particularly characteristic. The conidia are produced in quantity upon affected leaves placed in a moist chamber. The conidia are usually four-septate with the three central cells dark colored. The hyaline apical cell is furnished with from three to four filiform appendages, and the basal cell has a single shorter appendage. It is interesting to note that in the germination of this fungus one or more germ tubes are developed from the basal hyaline cell. The fungus grows vigorously in artificial culture. The mycelium is hyaline, and it develops a pinkish color when the acervuli are formed. The spores appear in about ten days after sowings are made if conditions are favorable.



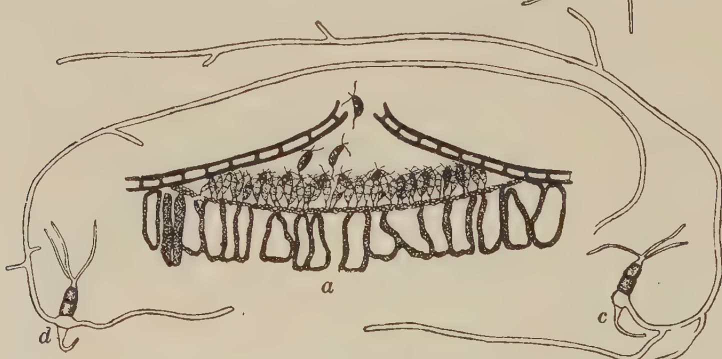


Fig. 161. *Pestalozzia Guepini.* (After Shear)
a, acervulus; *b*, conidia; *c* and *d*, germinating conidia

Pestalozzia Hartigii Tub. is a fungus of importance in forest tree nurseries where it attacks the seedlings of young trees of pine

and other conifers, as well as those of some deciduous trees, causing a shrinking of the bark around the young stem, and later a swelling above the injured area. The affected portions may be killed, and the injury results in time in the death of the plant.

XXXIX. SHOT-HOLE DISEASE OF PLUM AND CHERRY

Cylindrosporium Padi Karst

ARTHUR, J. C. Plum-Leaf Fungus. N. Y. Agl. Exp. Sta. Rept. **8**: 293–298. *figs. 6–10.* 1889.
STEWART, F. C., and EUSTACE, H. J. Shot-Hole Fungus on Cherry Fruit Pedicels. N. Y. Agl. Exp. Sta. Rept. **20**: 146–148.

Host relations. Many of the leaf-spot fungi occurring upon certain varieties of plums, cherries, and other stone fruits are to a considerable extent "shot-hole" fungi. In such cases the more or less circular injured area is separated by a line of cleavage from the healthy tissue, the injured tissue within this area promptly contracting, drying, and falling out. Cylindrosporium is responsible for the greater portion of this shot-hole trouble on many varieties of plums and cherries in America. On some varieties of the domestica type, as also on some cherries, the fungus may be common, producing spots only, or with inconspicuous shot-hole effects. This is also true of the Mahaleb cherry. The Japanese plums, on the other hand, show a

FIG. 162. SHOT-HOLE DISEASE OF CHOKE CHERRY

very pronounced shot-hole effect. Varieties of *Prunus americana* are frequently free from this fungus.

Where a species or variety is subject to shot-hole diseases a shot-hole effect may also be produced upon the leaves by spraying with any substance injurious to the leaf. When the leaves are so severely injured that the spots coalesce, the large irregular pieces may fall out in the same manner as just indicated. In any case the effects of shot-hole troubles on the leaf are frequently very severe, so that practically complete defoliation of the trees may take place by midsummer.

FIG. 163. CULTURE OF *CYLINDROSPORIUM PADI*

The fungus. In many cases the development of the acervuli of the fungus is not evident before the diseased areas have fallen away, but varieties in which the injured areas are persistent exhibit the fruiting pustules in great quantity. In such cases the spores may be seen to issue from the acervulus in tendril-like masses which are quickly spread out over the surface by dew and other agencies, appearing at first as a pale or ashen coating, becoming darker after a few days. The conidiophoric layer is often extensive and closely beset with the minute conidiophores (Fig. 164). The spores are curved and measure ordinarily

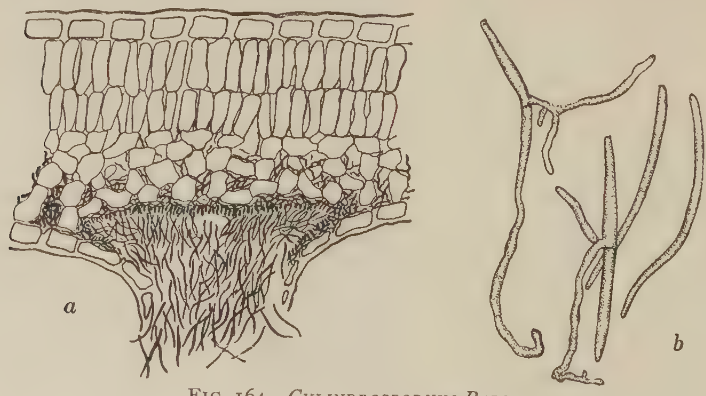


FIG. 164. *CYLINDROSPORIUM PADI*

a, section of acervulus ; *b*, conidia, some germinating

$48-60 \times 2\,\mu$. They germinate readily, and evidently require but a few days' incubation after infection for the production of the characteristic shot-holes upon susceptible hosts.

No ascogenous stage of this fungus is known, and there is some doubt as to the ordinary method of wintering over. Stewart, however, has found the pustules of this fungus on the twigs of cherry, and it is quite probable that this is one method of insuring its transmission from season to season.

Control. This, as well as other shot-hole-producing fungi, may be controlled by the use of neutral or alkaline dilute Bordeaux mixture, although the use of Bordeaux may be accompanied by injuries to the foliage. Weather conditions seem to affect greatly its relations to foliage injuries, and this is particularly true with respect to the peach and Japanese plums. In any case, however, thorough spraying with strong Bordeaux should be given in the early spring, whereas proper cultivation should be expected to destroy leaves harboring the fungi from the previous year.

XL. FRUIT SPOT OF APPLE [1]

Cylindrosporium Pomi Brooks

BROOKS, CHARLES. Fruit Spot of Apple, a Morphological and Physiological Study. Bullt. Torrey Bot. Club **35**: 423–456. *pls. 29–35.* 1908.

Occurrence and symptoms. This disease is of common occurrence in New England and is found in New York, Michigan, Ontario, and probably in other sections of the United States and Canada. The Baldwin is especially susceptible, but nearly every New England variety is more or less affected.

The disease appears about the middle of August as minute spots or specks on the surface of the apple. At first these are indicated merely by a deeper red color of the skin, if situated upon the colored part of the fruit, or by a green color, if situated upon the lighter portion. As the apple ripens the spots enlarge and many of them become brown and sunken, giving the fruit an unsightly

[1] This account of the fruit spot was kindly prepared by Professor Charles Brooks, New Hampshire College, Durham, N.H.

appearance which often greatly depreciates its market value. The tissue beneath the spots is dry and brown.

The fungus. The first studies upon this disease seemed to indicate that it was not produced by a fungus, but recent studies have demonstrated the causal relation of a fungus which seems to be properly a species of Cylindrosporium, as the title suggests. The mycelium is hyaline, septate, and intercellular. Chlamydospores are common in the host tissue. In late stages of the disease a compact stroma develops just beneath the epidermis and finally

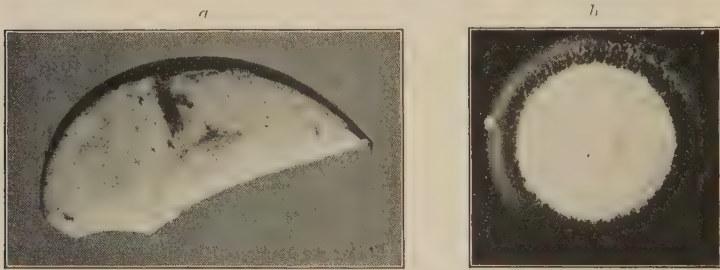


FIG. 165. *CYLINDROSPORIUM POMI.* (Photographs by Charles Brooks)
a, spot induced by inoculation of apple; *b*, mycelium in agar

breaks through it to expose spores and sporophores. The spores are hyaline, from one to five celled, and variously curved and contorted. They are from 2 to 2.5 μ in diameter and from 15 to 80 μ long. The chlamydospores and stromata are probably the agencies that carry the fungus over the winter. Under ordinary conditions of preparing separation cultures this fungus does not readily grow, and agar will ordinarily dry out before the fungus becomes noticeable. On this account it has seemed to be a difficult organism to isolate. As a matter of fact, however, under ordinary constantly moist conditions or in liquid media it grows readily.[1]

Infection probably takes place in July or August when the stomata are being torn open and the protecting layers of the lenticels are not yet formed, a season when the metabolism of the apple is extremely great and the transpiration stream necessarily large.

[1] The "Stippen" disease, long known in Europe and now reported from several parts of the United States, is regarded as entirely distinct, and probably not of fungous origin.

Control. This disease is readily controlled by spraying with Bordeaux, and weaker fungicides are often very effective. Sprayings made as late as July have been found to entirely prevent the disease.

Cylindrosporium Chrysanthemi Ell. & Dearn[1] produces blotches, commonly termed blight, upon the leaves of some varieties of the cultivated chrysanthemum. It may become epidemic at the time that the flowers are opening, apparently due to lessened vitality of the lower leaves.

XLI. HEART ROT AND BLIGHT OF BEETS

Phoma Betæ Frank

Frank, B. Ueber die biologischen Verhältnisse des die Herz und Trockenfäule der Rüben erzeugenden Pilzes. Ber. d. deut. bot. Ges. **13**: 192–199. 1895.

Frank, B. Die Pilzparasitären Krankheiten der Pflanzen. *l.c.* pp. 399–403.

Krüger, F. Die bis jetzt gemacht Beobachtungen über Frank's neuen Rübenpilz Phoma Betae. Zeitsch. f. Pflanzenkr. **4**: 13–20. *fig. 1.* 1894.

Habitat relations. This is one of the most serious diseases of the sugar beet in portions of Germany, Austria, and France. It begins to manifest itself as a rule in August by blackening and drying of the younger heart leaves, and later older leaves also succumb, so that before the period of harvesting all the leaves may be dead and merely the beet stub remain. In cases where the beets are grown for seed, the fungus may also be found upon the seed stalks and cases. It is thought that this is one means by which the fungus may pass over from one year to the next. From the affected leaves, particularly along the course of the fibrovascular bundles, the browning and general discoloration of the tissues extend into the tissues of the root, and there rot sets in. If the disease begins early in the season great injury may be done. It is considered probable that this organism was a chief agent in the great losses sustained by beet growers in Europe during the middle of the nineteenth century, and the organism was certainly again unusually prevalent and destructive in 1892–1893. Frank considers the *Phyllosticta tabifica* Pril. & Del. to be the same

[1] Halsted, B. D. Recent Chrysanthemum Blight. N. J. Agl. Exp. Sta. Rept. **15**: 365–368. 1894.

organism as the one here described. It was also thought by these French observers that a Sphærella which was found associated with the Phyllosticta might be a perfect stage of the latter species.[1]

Pycnidia are produced over practically all the dead portions of the plant, especially, however, on the leaves and leafstalks. These are small, more or less spherical bodies, with slightly depressed ostiola; pycnidia measure up to 200 μ in diameter. The fungus grows readily in artificial culture media, and it has been used by Saida in some interesting experiments on the fixation of atmospheric nitrogen. Frank states that the spores may remain alive in moist soil throughout the winter without germinating, and then, upon being placed in beet decoction, germination will promptly proceed.

Control. Spraying experiments have not yet given complete satisfaction. Care should be taken to destroy such remains of the previous crop as is practicable, and the treatment of seed with Bordeaux mixture is desirable where disease abounds. Fortunately this fungus has not made its appearance in this country up to the present time.

XLII. DRY ROT OF SWEET POTATO

Phoma Batatæ Ell. & Hals.

Halsted, B. D. Some Fungous Diseases of the Sweet Potato. Dry Rot. N. J. Agl. Exp. Sta. Bullt. **76**: 23–25. *fig. 16.* 1890.

This fungus is not uncommon in New Jersey, but it is not to be considered one of the more serious enemies of the sweet potato. A comparative study of this species and of forms upon related hosts has not been made, and it is possible that it may be referred to a species described earlier. It attacks the root, which shows the effect of the invading organism only by a gradual shriveling and discoloration of the affected areas. The whole root may become affected, and eventually dry and powdery. The pycnidia appear upon the surface in large numbers, and the fungus spreads rapidly during storage of the roots under moisture conditions. The effects of this fungus are frequently complicated by those of other organisms attacking the root, especially certain forms producing soft decay.

[1] Bull. Soc. Myc. de France **7**: 15–19. 1891.

XLIII. SEEDLING STEM BLIGHT OF EGGPLANT

Phoma Solani Hals.

HALSTED, B. D. Some Fungous Diseases of the Egg Plant. N. J. Agl. Exp. Sta. Rept. **12**: 277–279. 1891.

This fungus has much the habit of a damping-off fungus, infesting the young seedlings of eggplant near the surface of the ground before they are removed from the hotbed. The diseased portion

FIG. 166. BLIGHT OF SNAPDRAGON; PLANTS AT THE RIGHT AND LEFT, INOCULATED WITH *PHOMA HERBARUM* (?): CENTER PLANT, CONTROL

is first water-soaked in appearance. Later this area shrivels, and the diameter is much less than that of the healthy stem beyond. Infected seedlings seldom survive. The pycnidia are produced abundantly on the drying areas.

XLIV. PHYLLOSTICTA

Phyllosticta Paviæ Desm. The leaf blotch caused by this fungus is probably the most important malady of the horse-chestnut. The irregular spots develop rapidly as the season advances, and the larger part of the leaf may become involved, from the margin to

the midrib, as if sunburned. Eventually the leaves fall prematurely and the vitality of the tree is greatly affected. The perithecia appear on the upper surface of the leaves, but are not usually present, at least abundant, over the whole affected area.

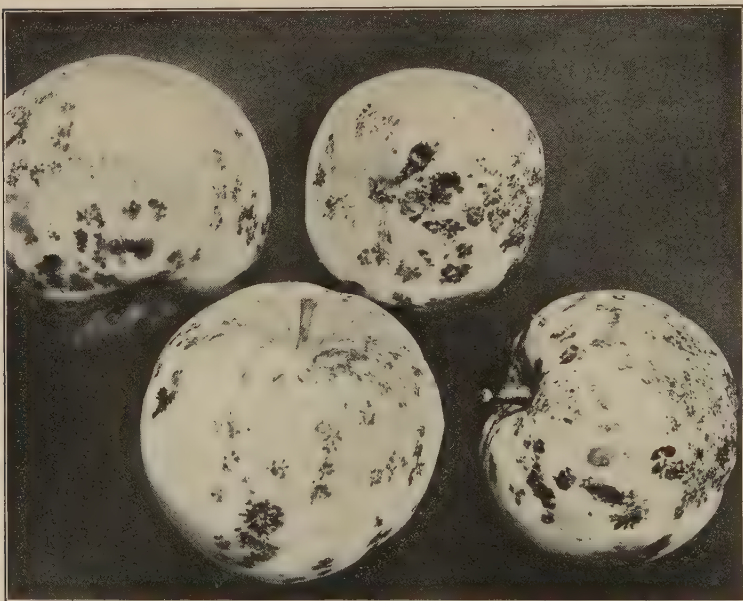


FIG. 167. *PHYLLOSTICTA SOLITARIA:* APPLE BLOTCH

Phyllosticta hortorum Speg.[1] occurs both upon leaves and fruit of the eggplant (*Solanum Melongena*), producing upon the latter soft spots which become shrunken and decayed, rendering the fruit worthless.

Phyllosticta solitaria E. & E. A fungus producing a destructive fruit blotch[2] of the apple in the South has recently been identified as the above species. The disease is more common upon the light colored varieties of this fruit.

[1] Halsted, B. D. Some Fungous Diseases of the Egg Plant. The Leaf-Spot Fungus. N. J. Agl. Exp. Sta. Rept. **12**: 279–281. 1890.

[2] Scott, W. M., and Rorer, J. B. Apple Blotch. Bureau Plant Ind., U. S. Dept. Agl. Bullt. **144**: 1–28. *pls. 1–6.* 1909.

Phyllosticta maculicola Hals.[1] is the cause of a very common leaf spot of several species of Dracæna and Cordyline. The spots are characterized by pale centers and reddish or purplish borders. The disease is sometimes severe in greenhouses where it has long been allowed to proceed unchecked. It is, however, readily prevented by spraying with potassium sulfide solution.

FIG. 168. DRACÆNA LEAF BLIGHT

Phyllosticta Ampelopsidis Ell. & Mart. is perhaps closely related to the fungus causing black rot of the grape. It has been injurious during some seasons to the Boston or Japanese ivy (*Ampelopsis Veitchii*).

Phyllosticta Catalpæ Ell. & Mart.[2] is commonly found associated with *Macrosporium Catalpæ* on the leaves of several species of catalpa, but it is to the former fungus that the production of the spot is now ascribed.

Phyllosticta Violæ Desm. occurs upon the violet and the pansy, often causing blotch-like, pale spots which may result in considerable injury.

Phyllosticta Magnoliæ Sacc. produces a very definite spot disease on the leaves of *Magnolia grandiflora* in Europe.

Phyllosticta Pyrina Sacc. was long supposed to be a chief cause of the apple leaf spot so common in the United States. Recent work indicates that the spot is in general primarily due to Sphæropsis, and that the Phyllosticta is to be regarded as taking a minor part in the production of the injury. In fact, the failure of inoculation experiments (see Sphæropsis, p. 352) appear to demonstrate that the latter is saprophytic, at least with respect to penetration.

[1] Halsted, B. D. Blights of Dracænas. N. J. Agl. Exp. Sta. Rept. **14**: 412. 1893.

[2] Scribner, F. L. Leaf-Spot Disease of Catalpa. U. S. Dept. Agl. Rept. (1887): 364–369.

XLV. BLACK ROT OF SWEET POTATO

Sphæronema fimbriatum (Ell. & Hals.) Sacc.

HALSTED, B. D. Some Fungous Diseases of the Sweet Potato. The Black Rot. N. J. Agl. Exp. Sta. Bullt. **76**: 7–14. *figs. 3–10.* 1890.

HALSTED, B. D., and FAIRCHILD, D. G. Sweet-Potato Black Rot. Journal of Mycology **7**: 1–11. *pls. 1–3.* 1891.

The black rot of the sweet potato is one of the most destructive diseases of this host, and it is known to occur from New Jersey southward practically throughout the Atlantic coast region. The distribution of the fungus, however, is not completely known. The disease may appear in the seed bed, resulting from the use of infested seed roots. The disease upon the seedlings is known as black shank, due to the black spots or discolorations on the roots and young stems. The commercial root may be infested either as a result of planting diseased slips, or the infection may be due to the presence of the fungus in the soil. Upon the full grown root the disease appears in the form of dark patches or decayed spots, which, upon more careful examination, and especially upon removal of the skin, will appear green. These spots vary in size from minute flecks to extensive areas involving practically the whole root. When the roots are diseased there is no appearance of the vegetative parts which suggests the presence of the parasite.

The fungus. The mycelium consists of septate, much branched, thick-walled, olivaceous hyphæ, which are commonly intercellular. The cells in the region invaded are robbed of starch, and the cell walls are brown and often collapse. The fungus has many fruiting stages which may be briefly referred to. Two kinds of conidia are produced, one within the tissues consisting of simple, ovate, greenish cells, abscised from terminal or lateral branches. Upon the surface of the diseased area, or in culture, there are also produced minute, hyaline conidia. The latter are developed endogenously, more or less as described for a similar phase in the case of the root rot of tobacco, *Thielavia basicola*. The pycnidial form is produced within the diseased areas, and it is also readily developed in artificial cultures. It consists of a flask-shaped pycnidium, with extremely long neck. The bulbous portion is from 96 to 224 μ in diameter and the neck from 395 to 608 μ in length, and 24–34 μ wide at the base, tapering to 12–14 μ. The method of spore

production in the pycnidium has not been clearly made out, but the spores are unicellular, and, when mature, ooze out from the tip of the flask-shaped body, adhering in masses. They are more or less subglobose or oblong, hyaline, and measure 5–9 μ in length. Upon immersion in water they increase greatly in size and readily germinate.

When the mycelium has developed to a considerable extent in the root, sclerotia of large size appear. It is believed that these sclerotia may be properly a phase in the life history of this species, and that they may also be important in the perpetuation or spread of the fungus. This fungus will continue its growth and development upon the stored roots, and also upon the remnants of the crop left in the field, so that special care must be taken not only with respect to the quality of the roots used at the time of planting, but also to the prevalence of the disease during previous years in the fields where potatoes are to be grown.

The sunken area and the greenish character of the diseased portion enables one readily to distinguish the effects of this fungus from those produced by the common black mold, *Rhizopus nigricans* Ehr., which is the organism causing the typical soft rot of this crop. The latter disease is not discussed in this work.

Proceeding from the mycelium within the tissues the Sphæronema has been readily cultivated upon various artificial media. In cultures upon sweet potato agar a profuse mycelium is developed. The submerged hyphæ are olive brown in color and contain abundant oil droplets. All three types of spores are produced, aërial hyphæ originating the endogenous spores, and submerged sporophores producing the olivaceous conidia. Normal pycnidia develop in culture in a week or more. The disease has been produced in healthy roots by inoculation with the hyaline conidia and with the pycnospores from pure cultures.

Control. Seed roots for planting purposes should be carefully selected and no slips should be taken from plants in the seed beds showing disease. Rotation of crops is necessary to rid fields of this fungus. Apparently no experiments of interest have been made to determine the possibility of preventing the spread of the fungus in stored roots. Nevertheless, any conditions favoring the accumulation of moisture would be favorable to the organism.

XLVI. BLACK ROT AND CANKER OF POMACEOUS FRUITS

Sphæropsis Malorum Pk.

HALSTED, B. D. The Black Rot of the Quince. N. J. Agl. Exp. Sta. Bullt. **91**: 8–10. 1892.
PADDOCK, WENDELL. The New York Apple-tree Canker. N. Y. Agl. Exp. Sta. Bullt. **163**: 331–360. *pls. 28–33.* 1899.
PADDOCK, WENDELL. Ibid. (Second Report) N. Y. Agl. Exp. Sta. Bullt. **185**: 205–213. 1900.

Habitat relations. Under the specific name given above a fruit decay of apples, quinces, and pears has become well known although

FIG. 169. *SPHÆROPSIS MALORUM* ON APPLE. (Photograph by H. H. Whetzel)

not serious in the United States. More recently it has developed that this fungus is likewise the cause of an important form of canker on trunks and limbs of the same fruit trees. It has been extensively studied only in New York (Paddock). Owing to the occurrence, however, of a variety of cankers on the apple tree, this one is frequently designated "the New York apple canker." This canker has been found to occur in many of the northeastern

and northern central states, as well as in Canada, and it is not improbable that it is more or less distributed throughout the country. Under other scientific names, moreover, it may also be known botanically, at least, in Europe.

FIG. 170. THE SPHÆROPSIS CANKER OF APPLE (Photograph by H. H. Whetzel)

As a rot of fruit the fungus is more generally known in America. It is a brown rot, beginning as a small spot, frequently near the bud end of the fruit, and spreading until the whole fruit may be involved. There is not such characteristic shrinkage of the tissues as in the case of the bitter rot. The pycnidial pustules may begin to appear when the spot is only half an inch in diameter, or they may not become evident until the entire fruit is decayed. This rot often attacks the fruit on the trees, yet it is far more common upon the neglected fallen fruit (Fig. 169), which is a great source of danger to the health of the tree. In the mildest form the canker is believed to cause merely a greater roughening of the bark, an injury which may occur as a single spot, or which may extend along the limb for a distance of several feet. In the most serious cases it first destroys the bark, well-marked depressed areas being developed, about which local swellings of the limbs occur, and in these affected areas the wood at the center

may be exposed, or extensive wounds may result. The disease is more common upon the larger limbs of older trees, but trunks and twigs are not exempt, and young trees may suffer. When complete girdling results, the limb is killed, yet serious consequences may gradually develop without girdling. Fig. 170 shows an early stage of this canker.

Infection is probably most frequent in the spring. It is believed upon good evidence that the worst wounds occur only when the fungus gains entrance to the edge of the wood through wounds. Trees which sunscald badly on the parts exposed to the direct rays of the southwest sun are as a rule subsequently infested with canker. In New York the Spitzenburg and Twenty Ounce are mentioned as the most susceptible varieties of apple to the limb canker, while Baldwin, Wagoner, Greening, and King follow in the order given; the Tallman Sweet was reported practically resistant. The susceptible varieties of pear are not known. In some cases, at least, the body blight of pear is also to be attributed to this canker organism.

Infrequently a Sphæropsis has been found upon the leaves of the pear, and this form appears to be similar to the canker fungus.[1] It is thought that general neglect, crowding, lack of pruning, etc., encourage the canker, although it may appear in vigorous orchards. There would appear to be absolutely no doubt that the rot of apples, pears, and quinces is due to the one fungus. Transfers of this organism are readily made. Paddock made many pure cultures as well as many transfers of the canker strains to fruits and vice versa, also to a variety of other hosts. The inoculation

[1] From extensive experiments made during 1907 by Scott and Rorer, it has been demonstrated that the common leaf spot of the apple, as it occurs east of the Rocky Mountains, is also generally traceable to *Sphæropsis Malorum* Pk. as a primary cause. The other fungi which have been associated with the apple spot, such, for instance, as *Phyllosticta Pyrina* Sacc. and *Phyllosticta limitata* Pk., have not been found to induce leaf spots upon inoculation. From young spots the Sphæropsis colonies are constantly plated out, and the other fungi mentioned were only present during the later stages of the disease. Moreover, inoculation experiments with the former have almost invariably yielded positive results within from five to ten days. These observers are of the opinion, therefore, that neither Phyllosticta nor other forms which may be found upon those spots are of any special importance in the apple orchard. (Scott, W. M., and Rorer, J. B., Apple Leaf-Spot caused by Sphæropsis Malorum. Bureau Plant Industry, U. S. Dept. Agl. Bullt. **121**: 47–54. 1908.)

experiments suggest that *Sphæropsis Mali* (West) Sacc. on bark, *Sphæropsis cinerea* (C. & E.) Sacc., and *Sphæropis Malorum* Pk. are properly the same fungus. Until, however, more careful comparisons shall have been made, we may continue to refer to this disease-producing fungus as *Sphæropsis Malorum*. It may be, moreover, that it occurs upon many other hosts.

The fungus. The mycelium is sooty brown or olivaceous within the tissues. It penetrates the bark readily but may not

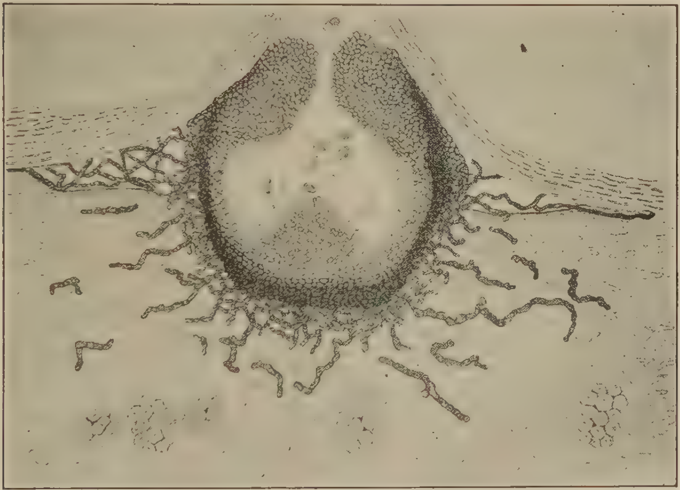


FIG. 171. *SPHÆROPSIS MALORUM:* MATURE PYCNIDIUM. (Photograph of a drawing by F. C. Stewart)

extend far into the wood. The pycnidia are erumpent, usually surrounded by a broken epidermis (Fig. 171), and they appear in cross section somewhat depressed-conical at the apex. The spores are oblong-elliptical, brown, and usually about twice as long as broad, measuring in general $22-32 \times 10-14\,\mu$. It has been found that the average sizes of the spores of the forms on apple, pear, and quince vary according to the host and part attacked. The most noteworthy difference is that upon the limbs the spores are smaller than on the fruits. The spores seem to retain their vitality for a considerable period of time, having been germinated after being stored for a year in the laboratory. On agar the fungus develops

effuse colonies, the aërial portions of which are at first gray, becoming darker with age. The pycnidia may sometimes be produced in agar and also upon various solid media in tube cultures.

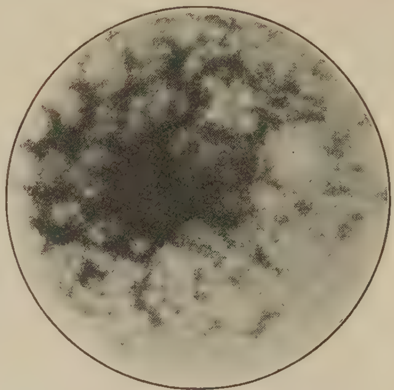


Fig. 172. Isolation Culture of *Sphæropsis Malorum*

Control. Preventive measures have not been carefully worked out. Under ordinary circumstances orchards in good condition will suffer least. Advantage may also be derived from treating the limbs and trunk thoroughly with any "cleaning up" washes, or with Bordeaux mixture. For varieties susceptible to sunscald, after which the canker may be common, it is recommended to give a winter spraying with whitewash. Pruning and scraping may also be required, and along with this the wholesale destruction of affected limbs or fruit.

XLVII. RASPBERRY CANE BLIGHT

Coniothyrium Fuckelii Sacc.

Stewart, F. C. Raspberry Cane Blight and Raspberry Yellows. N. Y. (Geneva) Agl. Exp. Sta. Bullt. **226**: 331–366. *pls. 1–6.* 1902.

Habitat relations. This is a fungus which, as a disease-producing organism, has been known only a few years; and it may be that the species is new. The botanical name given above is applied to a fungus which was described as occurring on a variety of shrubs and trees, the genus Rubus being among the hosts mentioned. Stewart and Eustace have tentatively referred the fungus causing raspberry cane blight to this variable species.

The cane blight is a widespread disease in New York state, and doubtless quite common throughout the country upon raspberries. It is essentially a wilt disease (Fig. 173), and the principal damage results to the fruiting canes. In some instances, however, young canes may be killed during the first season of growth.

FIG. 173. RASPBERRY CANE BLIGHT. (Photograph by F. C. Stewart)

Stewart states:

The whole cane may be involved or only a portion of it. Often a single branch is killed while the remainder of the cane continues alive and apparently normal. In the majority of cases only a part of the cane dies. With black caps the disease frequently starts in the old stub left in pruning. From

this point it gradually works downward, killing first the uppermost branch, then the next lower one, and so on until by the close of the berry harvest one-half of the cane or more may be dead. On black caps the disease also shows a tendency to work down one side of the cane, killing the bark and discoloring the wood on that side, while on the other side the bark remains green.

The disease occurs both upon black and red varieties of the raspberry, and it is thought that it may also injure dewberries. Cuthbert, Marlboro, Ohio, Gregg, Kansas, Superlative, I.X.L., and Pride of Geneva are varieties of raspberry which have been found to have been much injured in New York, while Columbian has proved notably resistant. The amount of damage which may be done when nonresistant sorts are grown is commonly estimated at from one fourth to two thirds of the crop. The disease doubtless spreads most rapidly during moist, warm summers, but its destructive effects upon the fruit crop are particularly noted during a season of drought.[1]

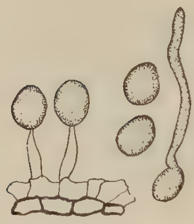


FIG. 174. *Coniothyrium Fuckelii.* (After Stewart)

The fungus. By the time that a cane is completely wilted there may be found at the base of the wilted portion a short area dead and discolored, in which appear the pycnidia. When expelled from the pycnidia the spores form brownish patches on the dead bark, or the dying canes might have a smutty appearance from the presence of numerous spores. Viewed singly the spores are very lightly colored, but in mass the brown color is pronounced. The spores measure $2.4–5 \times 2–3.5\ \mu$ (Fig. 174). Pure cultures of this fungus were obtained, but a description of growth characters has not yet appeared. Results from most carefully conducted inoculation experiments made from pure cultures have clearly demonstrated the parasitic nature of the disease, and the independence of Coniothyrium in producing it.

[1] Clinton thinks (Conn. Agl. Exp. Sta. Rept. (1906): 321–324) that the raspberry cane blight fungus gains entrance through the flowers and young fruit, the spores apparently being spread by bees and other insects. In Connecticut the black cap varieties have been more susceptible, special complaint having been made of serious injury to the Parmer, Cumberland, and Kansas. It has also, however, injured red varieties and occurs on wild black raspberries in the same region. He presents no further proof of the connection with Leptosphæria, but refers the fungus to that genus under the name *Leptosphæria Coniothyrium* (Fckl.) Sacc.

Control. It appears that the only practical methods of preventing this disease are to obtain healthy plants at the outset, to avoid planting where raspberries or other related plants have grown, and to remove and burn old canes as promptly as possible. The results with spraying have not thus far been successful.

XLVIII. ROSE LEAF BLOTCH

Actinonema Rosæ (Lib.) Fr.

COBB, N. A. Black Spot of the Rose. Dept. Agl. N. S. Wales. Miscel. Publ. (2d Ser.) **666**: 2–27. *Ill.* 1904.
SCRIBNER, F. L. Black Spot of Rose Leaves. U. S. Dept. Agl. Rept. (1887): 366–368. *pls. 8, 9.*

The rose leaf blotch, or spot, is perhaps the most common and injurious rose fungus aside from the powdery mildew (p. 224). This disease is characterized by more or less irregular brown spots, fairly well defined, on the upper surfaces of the leaves (Fig. 175), varying from a few millimeters in diameter to areas covering more than one half the entire leaflet. In this darkened area there are distributed a small number of pycnidia, producing numerous, elliptical, two-celled, hyaline conidia. This spot may be controlled by the use of any standard copper spray, but it is not, of course, desirable to spray for a few weeks preceding the blossoming period. Control measures should therefore look to preventing the disease from securing a start previous to the blossoming season.

FIG. 175. LEAF BLOTCH OF ROSE

There is considerable difference in the susceptibility of the different host varieties. As a rule the bushy sorts are more severely injured and the climbing roses are often immune. If cuttings are selected from healthy plants, even susceptible varieties may be generally propagated with little fear of serious trouble.

XLIX. LEAF SPOT OF THE PEAR

Septoria Pyricola Desm.

DUGGAR, B. M. Some Important Pear Diseases. Leaf Spot. Cornell Agl. Exp. Sta. Bullt. **145**: 597–611. *figs. 157–165.* 1898.

The leaf spot of pear is a disease which may be readily distinguished from the leaf blight subsequently described. It occurs throughout the eastern United States as an important fungus, both

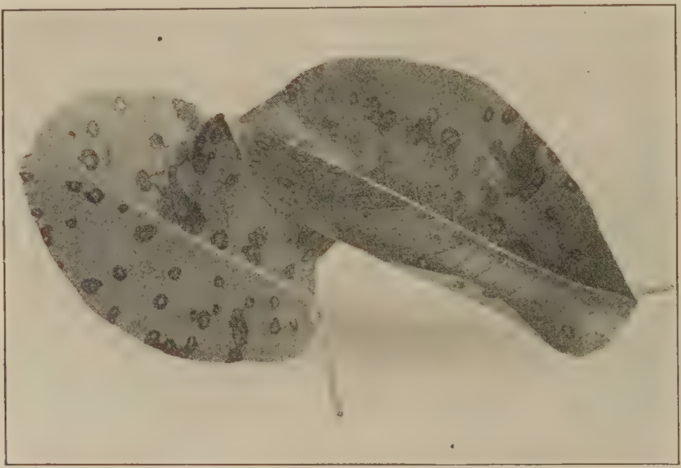


FIG. 176. LEAF SPOT OF PEAR

in orchards and nurseries. It is probably found throughout North America and is reported from various parts of Europe.

The leaf spot fungus is confined to the leaves, and in orchards the chief injury to trees may be the reduced vigor for the next season, due to premature defoliation. It is rather remarkable that while seedling apple stock in a nursery may show leaf blight to a considerable extent, adjacent plots of budded plants may be seriously injured by the leaf spot. The budded stock of the second year usually suffers more severely, particularly since it is generally less cultivated after the first season. In the state of New York most of the standard varieties may be attacked. Bosc, Anjou, Clairgeau, Seckel, Bartlett, etc., may be considerably injured, but Flemish Beauty, Duchess, and Winter Nellis are more resistant.

The Kieffer is practically exempt. In any case, however, the fungus may be readily controlled with Bordeaux.

The spots on the leaves are few or numerous, angular, and the size varies greatly with the variety. Three fairly well differentiated zones of color are shown in an affected spot: at the center it is ashen gray, and within this area appear on either surface the minute pycnidia; the next outer zone, or area, is brown, or black in very young leaves; and surrounding this second there may be an area

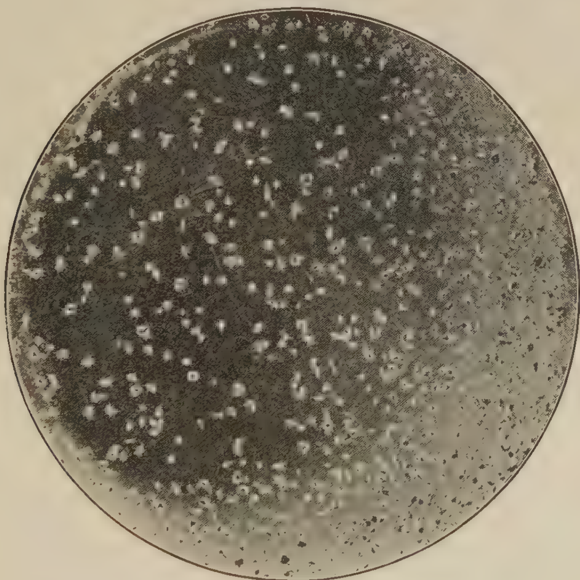


FIG. 177. DILUTION CULTURE OF *SEPTORIA PYRICOLA*

which is purplish in color (Fig. 176). These color details are lost in very old leaves, but the black papillæ indicating the pycnidia then show up clearly. At maturity the spores may ooze out in dark uniform cirræ. In cross section the pycnidium is clearly ovate in form. The wall is made up of several layers of dark cells, and the hyaline conidiophores arise from an inconspicuous inner layer (Fig. 178). The spores are flexuous and quite constantly two-septate, measuring about $60 \times 3\text{-}4\,\mu$. The mycelium is intercellular, brownish, and may be detected within the tissues at some little distance from the perithecium. The spores germinate readily in

FIG. 178. *SEPTORIA PYRICOLA:* SECTION OF PYCNIDIUM

nutrient media, germ tubes being pushed out from either end or from the middle (Fig. 179). This fungus has been readily cultivated upon bean stems and pear twigs, and I have reported the growth as follows:

Here the fungus grew slowly at first, producing after several weeks the pycnidia of the Septoria. After several transfers this fungus grows quite luxuriantly on bean pods or stems, as seen in figure . . . , producing the pycnidia in a short time, and the pycnidia are then not so definite in form but formed of a very loose stromatic mass. The submerged hyphæ are dark in color, while the aërial growth is dense and white, except the stromatic mass inclosing the pycnidium. I have had cultures for eighteen months; and although they have been subjected to various climatic conditions, nothing of further interest has as yet come from them. In nature the fungus is being closely watched for other stages, but I can say nothing definite upon this point at present, although other fungi have been found on the old leaves.

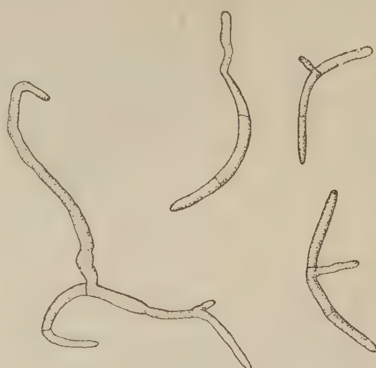


FIG. 179. *SEPTORIA PYRICOLA:* GERMINATING SPORES

Control. This fungus has been readily controlled in the orchard by the use of standard Bordeaux mixture applied as for pear scab. Where vigorous nursery stock would be produced, it is necessary to spray every season; but a single application, after the first flush of growth, is often sufficient.

L. LATE BLIGHT OF CELERY

Septoria Petroselini Desm., var. *Apii* Br. & Cav.

BEACH, S. A. Celery Septoria. N. Y. Agl. Exp. Sta. Bullt. **51**: 137–141. 1893.

DUGGAR, B. M. Late Blight of Celery. Cornell Agl. Exp. Sta. Bullt. **132**: 206–220. *figs. 48–60.* 1897.

Habitat relations. The late blight of celery is a comparatively recent disease in the United States, and in Europe it has not been considered a serious celery malady. It is most injurious as a rule during the early autumn, although a few spots of this disease may be seen at any time during the summer where it is at all prevalent. The spots are irregular in outline and of a rusty brown color. However, when the conditions are most favorable for the development of the disease, the fungus may spread over the whole surface of the leaflets without the formation of characteristic spots.

The late blight is destructive in the field until the plants are "lifted." It may also extend its injuries to the storage coop or cellar. The conditions in the storage cellar may be, during warm days of early winter, most favorable for the spread of the fungus. In a moist, poorly ventilated cellar I have found the pycnidia of this fungus over the surfaces of entire leaves, and the whole plant wilted as a result.

The fungus. The pycnidia of this fungus are evident soon after the spots turn brown, — as dark papillæ more or less in the center of the affected areas. The spores are slightly curved and septate, the septa being usually readily seen only by the use of stains.

Fresh spores germinate in a few hours in nutrient agar, and transfers may be made to bean stems and any other solid media for a more profuse mycelial development. Moreover, on solid media mature pycnidia may be secured within a few weeks. They develop superficially, and are then composed of loosely woven brown hyphæ. The mycelium is entirely distinct from that of *Cercospora Apii.*

Control. In the field Bordeaux or ammoniacal copper carbonate may be used as a spray, but in the storage cellar it is necessary to pay special attention to all matters of sanitation. When the disease is abundant in the field, additional risk is taken, of course, by placing the crop in storage.

LI. SEPTORIA: OTHER SPECIES

Septoria Lycopersici Speg., **leaf blight of the tomato.** The tomato is attacked by several leaf fungi which may become destructive, and of these fungi the one most injurious throughout the range of tomato culture is the organism causing what is known as leaf blight. The leaves are the parts most severely affected, and on these parts appear numerous small angular spots pale in the centers

FIG. 180. TOMATOES DEFOLIATED BY THE LEAF BLIGHT FUNGUS
(Photograph by H. H. Whetzel)

and with colored borders. The affected leaves have a tendency to curl dorsally throughout their length, eventually drying and falling. Petioles and twigs may also be affected, and small, elongate, dark spots may appear on the fruit.

The pycnidia are found on the upper surfaces of the leaves in the larger spots. It is probable that the fungus passes the winter in the old leaves and other refuse.

The use of Bordeaux mixture during the early part of the season has generally resulted in successful prevention.

Septoria Ribis Desm.[1] is common upon various species of Ribes. With respect to the economic hosts many varieties of both currants and gooseberries are subject to attack. Large spots with pale centers and brown borders are produced (Fig. 181). These are readily distinguished from those produced by the anthracnose (cf. Fig. 79) by the large size, the well-defined outline, and the pale central dead area. The pycnidia are found in small groups at the centers of the older spots. They are subspherical, and, when approaching maturity, crowded with spores arising from short filiform conidiophores. The conidia are long-filiform and measure 50–60 × 3–4 μ.

FIG. 181. LEAF SPOT OF CURRANTS
(Photograph by F. C. Stewart)

Septoria Rubi West produces numerous small spots, usually pale in the centers with colored borders, on the leaves of various species of Rubus, both blackberries and raspberries.[2] The fungus has been reported from many sections of the world, and is doubtless very generally distributed. Pycnidia are developed in the center of the larger spots, and these give rise to long tapering spores, 40–50 μ, ordinarily twice or more septate by rather indistinct divisions.

Septoria consimilis E. & M. The lettuce leaf spot, caused by this fungus, is prevalent on garden lettuce, particularly during the latter part of the season. It is perhaps the chief "spot" fungus of this plant, but may be held in check by the immediate destruction of the discarded and seeded plants in the field at the close of the season.

Septoria Dianthi Desm. produces small brown spots upon the leaves and internodes of the carnation. The leaves are often bent

[1] Pammel, L. H. Spot Diseases of Currants and Gooseberries. Iowa Agl. Exp. Sta. Bullt. **13**: 67–70. *figs. 15–16.* 1891.

[2] Ohio Agl. Exp. Sta. Bullt. **4** (6): 126. 1891.

or distorted. This disease is not likely to be serious where proper ventilation and subirrigation are provided for.

Septoria Chrysanthemi Cav. may become a serious pest upon the maturing leaves of the cultivated chrysanthemum.

LII. CURRANT CANE BLIGHT

Dothiorella

This disease appears to be most abundant in the Hudson Valley in New York. It has, however, been found in other sections, though not destructive. The affected canes are wilted and killed during midsummer. The disease is probably more easily seen during a dry period on account of the fact that when the water supply is abundant, it may not be noticeable during the growing season. The fungus producing this disease has been isolated from both the diseased wood and pith, and upon infection is capable of reproducing the disease. Several fruiting stages have been found, at least one of which is unquestionably a stage in the life cycle of this fungus. It has been difficult to identify all of the spore forms with certainty, but the pycnidial stage would be considered a species of Dothiorella (Fig. 182). Successful infection experiments with mycelium obtained from germinating pycnospores have been made. The relationship of this fungus to an ascogenous stage sometimes associated with it, or following it, upon the dead canes has been under careful study, but has not yet been reported. The fungus grows readily upon any of the solid nutrient media, producing a considerable gray-green mycelium.

FIG. 182. DOTHIORELLA ON CURRANT CANES

LIII. LEAF BLIGHT OF PEAR AND QUINCE

Entomosporium maculatum Lev.

DUGGAR, B. M. Some Important Pear Diseases. II. Leaf Blight. Cornell Agl. Exp. Sta. Bullt. **145**: 611–615. 1898.
FAIRCHILD, D. G. Experiments in Preventing Leaf Diseases of Nursery Stock in Western New York. N. Y. Agl. Exp. Sta. Rept. **11**: 642–652. 1892. (Also, Journ. Myc. **8**: 338–351.)
SCRIBNER, F. L. Leaf-Blight and Cracking of the Pear. U. S. Dept. Agl. (1888): 357–364.

Habitat relations. The leaf blight of the pear and quince has been observed in this country as well as in Europe for many years; it has also received considerable attention at various agricultural experiment stations in pear-producing regions. In New York it is most abundant apparently in the Hudson Valley, and in general it would seem to be more injurious in states in the Appalachian region. Nearly all varieties of pear are affected, but Duchess and Kieffer are perhaps the most resistant of those ordinarily grown. Moreover, in different regions of the Atlantic states there seems to be a difference in the susceptibility of varieties. Considerable damage may also be done in the nurseries to seedling pears, although grafted stock is far more subject to the leaf spot than to the leaf blight. Root suckers on seedling pears throughout the country are very generally injured. The spots are sometimes noticed on the tips of young branches, and it has been very definitely shown that in such situations the fungus may readily pass the winter. The effect of the disease upon seedlings is to harden the wood early and prevent the best results from budding.

FIG. 183. ENTOMOSPORIUM ON PEAR (Photograph by Geo. F. Atkinson)

Symptoms. The spots produced by this fungus are particularly evident on the upper surfaces of the leaves, occurring first as small discolored areas which become dull red at the center, with dark borders. They are more or less circular in outline, but they may be closely clustered and considerably confluent. In severe attacks the leaves may become yellow or brown, and they readily fall. This

disease is distinguished from the leaf spot by smaller spots more colored when young and more nearly circular. They are also less clearly defined on the under surfaces.

FIG. 184. ENTOMOSPORIUM ON QUINCE. (Photograph by H. H. Whetzel)

The blight also attacks the fruit. In this case the spots are at first red but later darker in color. The drying of the surface layers accompanying the effects of this disease may cause a cracking very much as in the case of pear scab.

The fungus. The larger spots of the leaf blight will generally show at the time of leaf fall one dark papilla in the center of each. This papilla is an indication of an acervulus, or spore-producing stroma. The mycelium from which this stroma originates penetrates the epidermal layer and also to some extent the hypodermal tissues, and the affected region shows a general collapse of the cells. From the subcuticular stroma there are produced on minute conidiophores numerous "insect-like" spores (Figs. 185, 186). The spores germinate readily and the fungus is thereby spread during the same season. Various authors have described what is supposed to be a perfect stage of this fungus. Sorauer[1] has referred the ascogenous stage to *Stigmatea Mespili*. Atkinson[2] has found this fungus on wintered leaves of the quince and has considered it to be a member of the genus Fabræa.

FIG. 185. *ENTOMOSPORIUM MACULATUM*

Control. Experiments upon nursery stock have shown that Bordeaux mixture of any standard strength may be used success-

[1] Pflanzenkrankheiten, *l. c.* (cf. p. 371). [2] Garden and Forest **10**: 73–74. 1897.

fully as a preventive. Five or more sprayings have been profitable upon American, French, and Japanese stocks, although this has not afforded complete protection. Spraying as for the pear scab is advised when this disease becomes a matter of sufficient economic importance in the orchard.

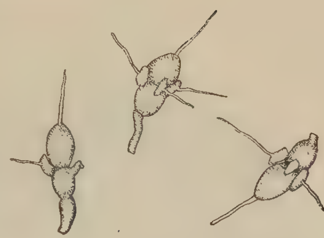


FIG. 186. SPORES OF THE ENTOMOSPORIUM

LIV. SOOTY BLOTCH AND FLY SPECK OF THE APPLE AND OTHER PLANTS[1]

Leptothyrium Pomi (Mont. & Fr.) Sacc.

CLINTON, G. P. Notes on Parasitic Fungi. Fly Speck. Sooty Blotch. Conn. Agl. Exp. Sta. Rept. (1903): 299–302.
POWELL, G. H. A Fungous Disease of the Apple. Garden and Forest **9**: 474–475.
SELBY, A. D. Sooty Fungus and Fly Speck Fungus. Ohio Agl. Exp. Sta. Bullt. **79**: 133–134.
STURGIS, W. C. On the Cause and Prevention of a Fungous Disease of the Apple. Conn. Agl. Exp. Sta. Rept. **21**: 171–175.

According to the unpublished observations of Floyd the sooty blotch and fly speck are apparently stages of the same fungus. They are almost invariably associated upon the host (Fig. 187), but may occupy distinct areas upon the same portion of the plant. They seem to occur upon the fruit of the apple throughout the limits of its culture. A sooty blotch and a fly speck are also found upon the pear, and along a roadside near Columbia, Mo., there were found more than twenty-five hosts affected by what was apparently the same fungus. These plants were all woody in texture, and the fungus occurred generally on the younger twigs and petioles. The forms upon these hosts may be provisionally referred to as one fungus. Observation indicates that the organism is most abundant under conditions of considerable moisture, half shade, and abundant dust. The market value of apples is affected by the discolorations which result.

[1] For the material of this account I am very largely indebted to unpublished data kindly furnished by Mr. B. F. Floyd of the Fla. Exp. Sta.

The mycelia of both the blotch and the speck are superficial, at most merely roughening the surface of the cuticle. The blotches are irregular in outline, sometimes coalescing into large areas. The specks, as the name indicates, are small, circular, dark colored flecks associated in groups, and sometimes distributed over large areas.

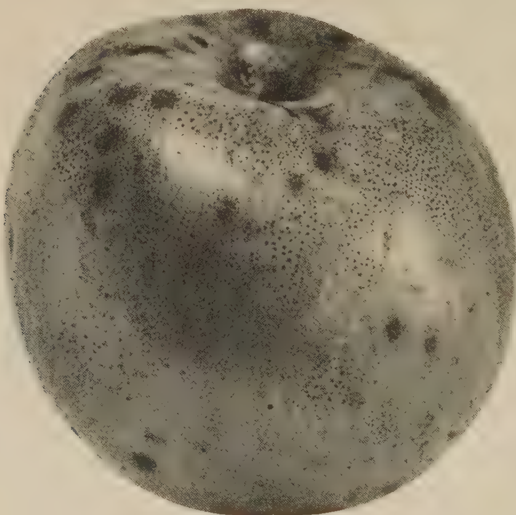


FIG. 187. FLY SPECK AND SOOTY BLOTCH OF APPLE

A network of radiating olive-brown or fuliginous hyphæ made up of more or less barrel-shaped cells constitute the blotch. Cell fusions and cell aggregations are common. On the other hand, the specks are at first dense aggregates of rather light colored hyphæ, and from such specks delicate hyphæ may be traced to similar neighboring spots or to blotches. A mature speck becomes shining black and dry. Then the central portion breaks away and is presumably the source of new infections. No spore form has been found accompanying this phase. Both types of fungus have, however, been followed

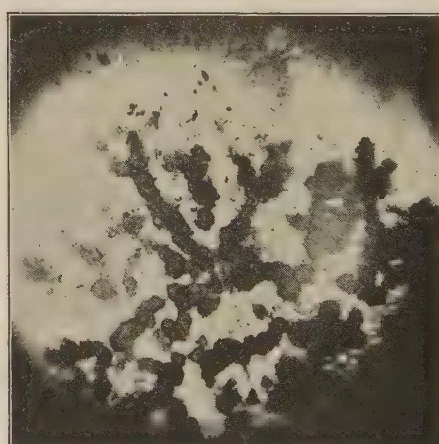


FIG. 188. *LEPTOTHYRIUM POMI:* DEVELOPMENT OF PYCNIDIA FROM PYCNOSCLEROTIA (Photograph by B. F. Floyd)

throughout the autumn and winter and careful sections made at different times. In the case of the blotch, as the season advances, the cell aggregates may develop a definite sclerotial-like body (November in Missouri). By March this body has differentiated into a pycnidium (Fig. 188) 25 to 100 μ in diameter, of the Leptothyrium type, bearing hyaline, elliptical spores. The latter measure 12–14 × 2–3 μ.

CHAPTER XIII

HEMIBASIDIOMYCETES

I. USTILAGINALES

BREFELD, O. Die Brandpilze, I. Unters. a. d. Gesammtgeb. d. Mykologie **5**: 1–220. *pls. 1–13.* 1883.

BREFELD, O., u. FALCK, R. Ibid. **13**: 1–75. *pls. 1–2.* 1905.

CLINTON, G. P. North American Ustilagineæ. Proc. Boston Soc. Nat. Hist. **31**: 329–529. 1905.

DANGEARD, P. A. Recherches histologiques sur la Famille des Ustilaginées. Le Botaniste **3**: 240–281. 1892.

DE BARY, A. Die Brandpilze. 144 pp. *8 pls.* 1853.

DIETEL, P. Ustilagineæ und Tilletiineæ. Natürl. Pflanzenfam. (Engler u. Prantl, Red.) **1** (Abt. 1 * *): 2–24. *figs. 1–13.*

FISCHER DE WALDHEIM, A. Beiträge zur Biologie u. Entwickelungsges. d. Ustilagineen. Jahrb. f. wiss. Bot. **7**: 61–144. *pls. 7–12.* 1870.

HARPER, R. A. Nuclear Phenomena in Certain Stages in the Development of the Smuts. Trans. Wis. Acad. Sci., Arts, and Letters **12**: 475–498. *pls. 8–9.* 1899.

PLOWRIGHT, C. B. A Monograph of the British Uredineæ and Ustilagineæ. 347 pp. *8 pls.* 1889.

TULASNE, L. R. et C. Mémoire sur les Ustilaginées comparées aux Uredinées. Ann. d. Sci. Nat. (Bot.) **7** (3 Sér.): 12–127. *pls. 2–7.* 1847.

The Ustilaginales, commonly known as the "smut fungi," represent, in the opinion of most mycologists, what may be considered the lowest of the basidium class. Without exception, they are parasitic fungi, and they occur upon herbaceous flowering plants. Many species infect grasses. There are, however, thirty-five families of host plants in North America alone, representing (according to Clinton) one hundred and sixty-four genera and four hundred and forty-two species.

The method of infection is diverse. In a few species infection is apparently limited to the germinating seedlings, in many cases, however, taking place through any meristematic tissues. The mycelium may extend throughout the entire plant or it may be located in limited areas, sometimes being confined to particular organs of the plant. It is commonly intercellular, frequently developing haustoria. Upon the production of spores it may disappear by a gelatinization process. Reproduction is seldom by

means of conidia produced on the external portion of the host, as in Entyloma, and typically by means of chlamydospores formed within interstitial or terminal cells or hyphæ. Chlamydospores are for the most part dark colored, simple or agglutinated, and with or without sterile appendage cells. The chlamydospores produce upon germination a basidium-like structure known as a promycelium, which in turn originates lateral or terminal sporidia. In this order the fusion of sporidia, or of germ tubes from these, is common. This cell fusion is not accompanied by nuclear fusion. Each sporidium is provided with a single nucleus.

This order is divided into two families, Ustilaginaceæ and Tilletiaceæ, based upon characters which become evident only in germination. The characters are therefore largely those of the germ tube or promycelium.

Ustilaginaceæ. Spore masses are made up of simple or compound spores. The promycelium is usually divided into two or four cells, originating both lateral and terminal sporidia, which sporidia, in saccharine or other nutrient solutions, are for the most part able to bud after the fashion of yeast fungi for an almost indefinite period of time. This family includes from seven to eleven genera, according to different authorities.

The characters of only three genera need to be considered in order to become familiar with the basis of classification.

1. Spores single, spore masses dusty at maturity and without any sort of inclosing membrane . . . . *Ustilago*
2. Spores agglutinated in balls, spore masses more or less dusty. Spore balls usually evanescent, spores very dark . . . . . *Sorosporium*
3. Spores agglutinated in balls, spore masses more or less dusty. Spore balls rather permanent, spores now adhering by folds or thickenings of the outer coat . . . . *Tolyposporium*

Tilletiaceæ. Spore masses are made up of simple or compound spores; these masses dusty and exposed, or imbedded in the tissues. The promycelium is short, originating usually an apical cluster of more or less filiform sporidia. The latter may fuse in pairs, and whether fusing or not, may produce secondary conidia, or may germinate directly into infection hyphæ.

This family includes from eight to ten groups of generic rank, the differentiated characters of three of which may be indicated.

1. Spores single, spore masses dusty, spores without conspicuous tube-like hyaline appendage . . . . *Tilletia*
2. Spores single. Spores in loose groups, imbedded in the tissues. *Entyloma*
3. Spores agglutinating in balls, spore masses dusty, spore balls invested with a cortex of sterile cells . . . . *Urocystis*

II. LOOSE SMUT OF OATS

Ustilago Avenæ (Pers.) Jens.

JENSEN, J. L. Om Kornsorternes Brand. Copenhagen, 1888.
KELLERMAN, W. A., and SWINGLE, W. T. Loose Smut of Cereals. Kansas Agl. Exp. Sta. Rept. **2**: 213–288. *pls. 1–9.* 1890.
KELLERMAN, W. A., and SWINGLE, W. T. Additional Experiments and Observations on Oat Smut. Kan. Agl. Exp. Sta. Bullt. **15**: 93–133. 1890.
STUART, W. Formalin as a Preventive of Oat Smut. Ind. Agl. Exp. Sta. Bullt. **87**: 1–26. 1901.
SWINGLE, W. T. The Grain Smuts. U. S. Dept. Agl. Farmers' Bullt. **75**: 1–20. *figs. 1–8.* 1898.

The loose smut of oats is one of the most common and destructive of the smut family. It is found wherever oats are cultivated, and it would not appear that climatic conditions influence materially the abundance of the fungus. Besides the various varieties of the cultivated oats (*Avena sativa*), it has only been reported upon *Avena fatua*, the latter in California.


FIG. 189. LOOSE SMUT OF OATS

Like most of the other loose smuts of grain, it matures at or about the time the grain is in flower, and during the ripening season it is widely distributed. The general appearance of the loose smut is striking, and usually as shown in Fig. 189. It has been estimated that the average loss to the oat crop throughout this country may be placed at about eight

per cent. This estimate would mean a loss of about twenty million dollars, based upon the statistics of oats produced during 1906.

The mycelium of the oat smut is present throughout the tissues of the affected plants. Infection takes place by means of the germinating conidia at the time of germination of the seed. The mycelium branches abundantly in practically all tissues of the developing flowers, completely infesting the young ovule and the inclosing floral structures. The mycelium, at the time that spore formation becomes evident, shows a nodulate appearance, and the branches are closely fascicled, like clusters of grapes. Within each swollen area of the mycelium a chlamydospore is found. As the chlamydospores mature, the inclosing walls of the parent hyphæ and much of the general mycelium which is not differentiated into spores gelatinizes or otherwise breaks away, and the spores are set free in large masses. With the increased growth of the mycelium and the formation of spores, the softer cells of the host plant are rapidly absorbed, so that at maturity only the more resistant tissues of the florets may remain, the whole ovule with its inclosing glumes being largely converted into the dusty mass of sooty spores. In a closely related species of oat smut (*Ustilago levis*), long regarded merely as a race or variety of *Ustilago Avenæ*, the mycelium destroys only the kernels and does not attack the glumes. The smut therefore remains inclosed or hidden.

The spores are almost spherical or slightly ovoidal, and echinulate, varying in length from 5 to 9 μ. They are also olivaceous in color, with a lighter area at one side. Germination of the fresh or of preserved spores may be readily secured. In fact, in herbarium material spores may preserve their vitality for several years. Germination may proceed in pure water or in nutrient solution.

The promycelium is frequently four-celled, though somewhat variable in this regard, and it often assumes abnormal forms, as shown in Fig. 190. The conidia are produced laterally and terminally. They are elliptical or subelliptical in form and measure $4.5–8 \times 4.5–6\ \mu$. In nutrient solutions the well-known budding of the conidia may continue almost indefinitely, and under certain conditions, or after extensive cultivation, mycelium-like cells may be produced. Upon the living host, however, the conidia germinate by the production of an infection hypha.

Control. In an endeavor to control smut in oats, bunt in wheat, and other more or less similar diseases, a careful study has been made of a variety of fungicides or toxic agents in solution, and of hot water.

The hot water treatment of the seed grain is the method in more common use. This method consists in immersing for ten minutes in water at a temperature of from 132° to 133° F. It has been found desirable to put the seeds into a basket or perforated tin vessel, and this may be previously dipped into warm water at a temperature of about 110° to 120° F., in order that the temperature of the hot water may not be greatly reduced by using cold seed. The water in which the seeds are finally immersed should be retained during the ten minutes at a temperature of not less than 130°, otherwise additional warm water should be added during the process. Furthermore, it is desirable to throw the seed into cold water before treatment, so that the smutted seed may be floated and skimmed off, for the treatment would be of small value if the large quantity of spores still held within the kernels of smutted grain were not removed. The hot water method is effective, but since it appears somewhat complicated, it is now being superseded by a formalin treatment. In its simplest terms the latter consists in dipping the seed in a solution containing 1 pint of formalin to 30 gallons of water. The seed may be put into sacks or baskets of from $\frac{1}{2}$ to 1 bushel each, and, as before, immersed in the barrel of formalin solution for about ten minutes, drained, put away wet in the sacks, or heaped and covered for two hours and finally spread out to dry rapidly before danger of germination. Shoveling over will facilitate the drying. Copper sulfate, potassium sulfide, and other germicides have also been employed.

FIG. 190. *Ustilago Avenæ:* Germinating Spores

III. LOOSE SMUT OF WHEAT

Ustilago Tritici (Pers.) Jens.

BREFELD, O., u. FALK, R. Unters. **13**: *l. c.* (Die Bluteninfektion bei den Brandpilzen).

FREEMAN, E. M., and JOHNSON, E. C. The Loose Smuts of Barley and Wheat. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **152**: 1–43. *pls. 1–6.* 1909.

SWINGLE, W. T. The Grain Smuts, *l. c.* (see *Ustilago Avenæ*).

The above species, producing the well-known loose smut of wheat, is almost as widely distributed as the organism producing the loose smut of oats. The general appearance of the affected plant at the time of flowering is much the same as in the case of oats, and in many respects the life histories of the two species are similar. This species is found upon practically all varieties of wheat and under all climatic conditions. Morphologically, this fungus is scarcely to be distinguished from the oats smut, and this is true whether one considers the form of the spores or the characters made evident upon germination; but the absolute failure of cross inoculations indicates that the two forms are distinct. According to recent investigations, moreover, it would appear that this species may also gain entrance to the host plant at the time of flowering. It is stated that the infection tube penetrates the stigma and style, and by that means enters the developing seed. In the developing seed it retains its vitality and grows up through the plant when the seed germinates. This mode of infection is said to be the most common; therefore, according to these results, treatment of the seed wheat for loose smut might seem to be useless; nevertheless, from experiments which have been made in this country, it would seem that a modified method of Jensen's hot water treatment is partially effective against this fungus. It appears at present possible to assign a cause for this latter fact. It does not seem to be due to a greater number of infections through seedling stages than is now assumed, and is presumably due to the killing of the fungus within the tissues by the hot water method.

Control. In view of the recent studies upon blossom infection, it would seem that the only reliable means of prevention would consist in the hot water treatment together with seed selection. It would be necessary to select seed from a field free of smut

Where the disease is very abundant it would be practicable, on plats to be employed for seed, to weed out smutted plants prior to final maturity. The most recent recommendation with respect to seed treatment is to soak five hours in cold water, and then ten minutes in water at 54° C.

IV. SMUT OF CORN

Ustilago Zeæ (Beckm.) Ung.

ARTHUR, J. C., and STUART, W. Corn Smut. Ind. Agl. Exp. Sta. Ann. Rept. **12**: 84–135. 1900.

HITCHCOCK, A. S., and NORTON, J. B. S. Corn Smut. Kan. Agl. Exp. Sta. Bullt. **62**: 169–212. *pls. 1–10.* 1896.

KNOWLES, E. L. A Study of the Abnormal Structures Induced by Ustilago Zeæ-mays. Journ. Myc. **5**: 14–18. *pls. 2–7.* 1889.

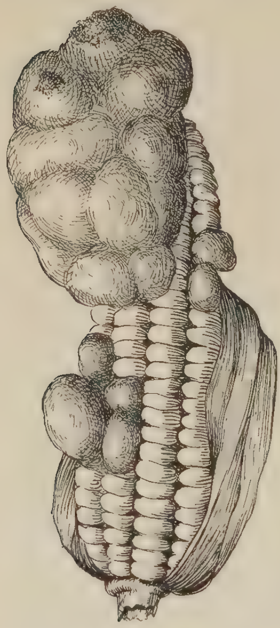


FIG. 191. *USTILAGO ZEÆ*: SMUT OF CORN

The common smut of corn (*Zea mays*) occurs in all regions where maize is grown. It is productive of considerable losses at times, and it is probable that in many corn-growing sections the yearly loss will average as high as 5 per cent. It may vary, however, from 0 to about 25 per cent.

Habitat relations. This fungus sometimes causes enormous enlargements of various parts of the host, occurring in staminate and pistillate flowers, on the stalk, especially at the nodes, and also in the leaves. The abnormalities or swellings are usually prominent and often attain the size of several inches in diameter. Very careful experiments throughout a long period of time have made it clear that infection takes place through any young and growing tissue, but that the plant is not affected, as a rule, until a foot or more in height. The spores retain their vitality in the soil for some time, and the sporidia may, by a sprouting process, be propagated and disseminated through manure or compost spread upon the land. The

mycelium is rather sparsely distributed throughout the general area of normal tissue, from which swellings arise, but it becomes developed at certain points in quantity in the form of pockets, in which areas it is later differentiated into the spores. Upon the stem the abnormal growth has been found to originate principally just beneath the epidermis, that is, outside of the area of the fibrovascular bundles. Rapid multiplication of the host cells occurs, and these become diverse and always abnormal in form. Neighboring bundles send branches into the abnormal tissue, and the bundles at some little distance may also show considerable variation from the normal type. At maturity cells of the host are very largely broken down, and the pockets of spores are surrounded by a membrane made up of modified fungous threads mingled together with dried host cells. This membrane is soon broken and the loose spores are set free. The spores are more or less spherical, though sometimes irregular, measuring often 8–12 μ, and the walls are beset with blunt echinulations. The spores germinate readily in water or in nutrient solutions in the normal manner. This fungus is known only upon one host besides the corn, that is, *Euchlæna luxurians*. One other species of smut is found upon the corn, *Ustilago Reiliana*, but this is readily distinguished from the common smut.

FIG. 192. *USTILAGO NUDA:* LOOSE SMUT OF BARLEY

Control. Since this fungus may gain entrance to the host at any time, prevention consists in cutting out the affected stalks before the spores mature. Such stalks, moreover, should be destroyed and not thrown upon the compost heap where the

fungus will multiply itself and be returned to the land in a form to do considerable damage to the crop the following season. It is commonly stated that fields heavily fertilized with barnyard manure develop a higher percentage of smutted corn.

V. SMUT OF BLUE-STEM GRASS

Sorosporium Syntherismæ (Pk.) Farl.

For the most part, the various species of Sorosporium occur upon the so-called blue-stem and poverty grasses, belonging to the genus Andropogon and Aristida. Several species are therefore common but of slight economic importance. *Sorosporium Syntherismæ* is found, however, upon several species of Panicum and Cenchrus, and is quite widely distributed throughout the United States. The sori are usually confined to the inflorescence, the whole of which may or may not be affected. At maturity they are inclosed in a false membrane, somewhat similar to that in *Ustilago Zeæ*, which ruptures, exposing the spore masses and shred-like remnants of host tissue. The spores adhere together in spore balls for a relatively short time, the balls being usually variable in shape, measuring from 50 to 100 μ in length. The spores are spheroidal or irregular in outline, measuring 9 to 13 μ, and they are covered with minute wart-like projections.

VI. TOLYPOSPORIUM BULLATUM (Schroet.) Schroet.

The above species is probably the most widely distributed of this genus in the United States. It occurs upon the common barnyard grass (*Echinochloa crusgalli*). The sori are confined to the ovule sacs, and, as in the preceding species, they are covered with a membrane which upon being ruptured exposes the spore balls. The latter are from 50 to 160 μ in length, black and opaque, consisting of one hundred or more closely united spores. The spores appear flavous or reddish brown. According to Clinton they are "covered with a thin, tinted, outer coat, more or less folded in ridges, by which the spores are bound together, and which, on the rupturing of the spore balls, often show as spiny projections at the spore margins, usually ovoidal, spherical, or polyhedral, 7 to 12 μ."

VII. BUNT, OR STINKING SMUT OF WHEAT

Tilletia fœtens (B. & C.) Trel.

KELLERMAN, W. A., and SWINGLE, W. T. Preliminary Experiments with Fungicides for Stinking Smut of Wheat. Kan. Agl. Exp. Sta. Bullt. **12**: 27–50. *pl. 1.* 1890.

KELLERMAN, W. A. Second Report on Fungicides for Stinking Smut of Wheat. Kan. Agl. Exp. Sta. Bullt. **21**: 47–72. 1891.

Distribution and symptoms. The above species is the more commonly distributed smut of this family upon grain in the United States, and while very commonly found in greater or less abundance, it is nevertheless entirely absent from some considerable wheat-growing regions. On the other hand, in portions of the Northwest, and extending also into Canada, there are regions in which the losses from this fungus have amounted to from one half to two thirds of a crop. The fungus affects the various varieties of wheat, but is not found upon any other grain. Little definite information, however, has accumulated concerning the susceptibility of different varieties to attack. The abundance of disease in certain regions would not seem to be greatly influenced by climatic conditions, but is probably very largely due to unfortunate practices in seed selection and to continuous cropping with wheat. The production of spores in the tissues of the host is confined very largely to the ovule sacs, at maturity the kernels being the chief seat of the spore masses. The spores are permanently concealed by the glumes which envelop the kernels; but smutted heads are more or less recognizable on account of a slight difference in color and a somewhat emphasized flaring habit of the spikes, due perhaps to slightly larger size of the infected kernels. The spores give rise to a penetrating and disagreeable odor, which becomes very evident in the bin or during the milling process. In general, all of the kernels of a spike will be infested.

The fungus. The spores are brown in color, usually oblong to spherical in form, with a smooth wall, varying considerably in size, extremes being more than from 16 to 25 μ in length. The germination of the spores of this species conforms well to the description given for the whole family. The acicular or needle-shaped sporidia, which are produced in the form of a crown on a short, continuous promycelium, frequently unite in pairs, and secondary sporidia

may be produced. Infection takes place through the young wheat seedling, and the spores are very generally distributed by means of the seed.

Control. Bunt of wheat has very generally been successfully treated by the methods recommended for oat smut. The formalin treatment is preferred. In applying this method, however, some prefer to sprinkle the wheat with the formalin solution (1 pint to 30 gallons) rather than to soak the seed.

VIII. TILLETIA: OTHER SPECIES

Tilletia Tritici (Beij.) Wint. This species also occurs upon the wheat and was long considered to be merely a spiny or reticulately marked form of *Tilletia fœtens*. Experiments have demonstrated that the fungi are distinct. This species is less frequently found, but when present it produces practically the same effects as those described for the fungus last discussed. It sometimes occurs in conjunction with *Tilletia fœtens*. A microscopic examination permits an easy identification, since the reticulations on the wall of the spore are marked in this species. The spores are very nearly equal in size to those of the preceding and measure 16–22 μ in diameter.

Tilletia horrida Tak. This fungus occurs in the ovaries of the cultivated rice, and it is now widely distributed in the United States as well as in the Orient. It is concealed by the enveloping blossoms and is not readily observed in the field. The spores are subspherical, measuring 22–33 μ in length. A band of scales 2–4 μ in width, due to the thickenings in the outer hyaline wall, is generally evident.

Tilletia corona Scrib. This species occurs upon plants related to the rice, namely, members of the genus Leersia, and it is common upon these plants in their natural habitats in the southern states.

IX. ENTYLOMA

Entyloma Physalidis (Kalchb. & Cke.) Wint. The smut fungi of the genus Entyloma are not commonly productive of conspicuous deformities. In the case of *Entyloma Physalidis* pale spots are produced upon the leaf of the ground cherry, or love-apple (*Physalis pubescens*). The spores are intermediate in size, 10–16 μ in length, and they are situated in small masses, or beds, scattered

throughout the affected areas. They are light in color, often nearly hyaline. The distribution of the spores is only effected by disintegration of the leaf. There are, however, conidia in the life history of some species of this genus of smuts. In this species they are scolecosporic in form, 30–55 × 1–2 μ. No very serious diseases of cultivated plants are induced by species of Entyloma, although the genus is rich in forms.

Entyloma compositarum Farl. is widespread in the United States upon a variety of the composites, including among these species of Ambrosia, Aster, Erigeron, etc. The minute sori occur in the leaves. The spores are subspherical or ovoidal, 9–14 μ, and hyaline. The under surfaces of the leaves may be profusely covered with the conidial form, which is in this case like a species of Cercosporella with relatively short spores and conidiophores. The conidia are fusiform or slightly clavate and measure 15–20 × 2–3 μ.

Entyloma Ranunculi (Bon.) Schröt.[1] is found upon various species of Ranunculaceæ. The life history of this form has been carefully studied.

X. ONION SMUT

Urocystis Cepulæ Frost

Selby, A. D. Onion Smut. Ohio Agl. Exp. Sta. Bullt. **122**: 71–84. *figs. 3, 4.* 1900.

Sirrine, F. A., and Stewart, F. C. Experiments on the Sulphur-Lime Treatment for Onion Smut. N. Y. Agl. Exp. Sta. Bullt. **182**: 145–172. 1900.

Sturgis, W. C. Transplanting, as a Preventive of Smut upon Onions. Conn. Agl. Exp. Sta. Rept. **19**: 176–182. 1895.

Thaxter, Roland. The "Smut" of Onions (*Urocystis Cepulæ*). Conn. Agl. Exp. Sta. Rept. (1889): 129–153. *pls. 1–2.*

Habitat relations. The onion smut has been known as an important disease-producing organism in the United States for about forty years, the first published notes of its effects being in the reports of the Massachusetts State Board of Agriculture, 1869 to 1870. The fungus seems to be of American origin and its injuries are very largely confined to the eastern states, particularly New England. It occurs, however, as far west as Indiana. It would not appear that climatic conditions affect the prevalence

[1] Ward, H. M. On the Structure and Life History of *Entyloma Ranunculi* (Bon.). Phil. Trans. Royal Soc. London. **178** B: 173–185. *pls. 3, 4.* 1887.

of the organism, nor does it seem that soil conditions are of any great importance. The host frequently shows the presence of the fungus soon after the first leaf appears. Dark spots are usually first noticed just below the knee of the first leaf, and these are frequently repeated in the leaves subsequently formed. The whole plant may therefore be very largely infected, although in exceptional cases the fungous mycelium seems to have directed itself into the first leaf and disappeared upon the withering of this organ. Soon after the spots are noticed upon the leaves longitudinal rifts are formed, and there are exposed threads of fibrous tissue, together with quantities of a granular spore powder, which latter consists of the characteristic spore masses or balls. Fig. 193, *a* shows an onion with a characteristic form of disease. The spore balls are washed into the soil, if diseased bulbs are not promptly removed, and the soil is unquestionably the chief source of the annual infection. It is possible that the spores may also adhere to the surfaces of the seed and thus further disseminate the fungus.

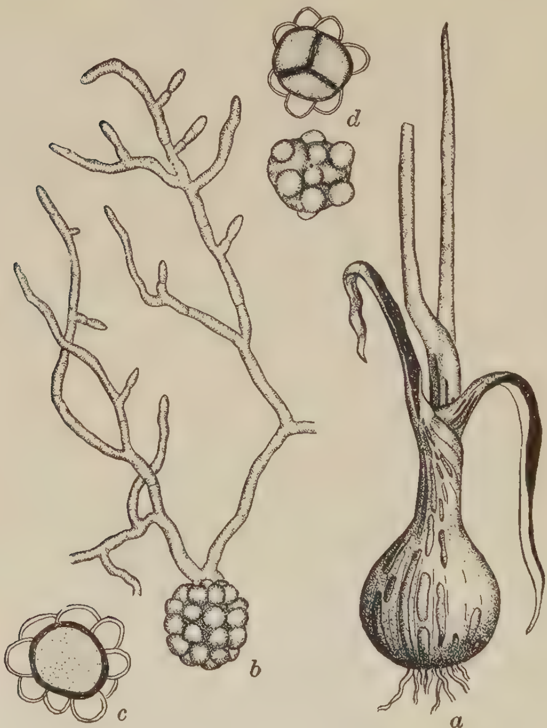


FIG. 193. UROCYSTIS, GENERAL CHARACTERISTICS
(*a*, *b*, and *c*, after Thaxter)

a, *b*, and *c*, *Urocystis Cepulæ*; *d*, *Urocystis occulta*

The fungus. It has been ascertained, apparently beyond doubt, that the spores may often retain their capacity for germination in the soil for a period of twelve years. The spore balls are more or less spherical in general outline and vary from 17 to 25 μ in greatest diameter. The spores in a ball may number several, but frequently only one is present. The sterile cells, which usually form a complete envelope, are slightly colored, generally subspherical in form, 4–8 μ in length. The germination, which has been carefully figured, commonly conforms to that of this family of fungi (Fig. 193, *b*).

Control. Since infected soil is the chief source of trouble, it is practically useless to treat the seed. The most effective method of prevention is that of transplanting the seedlings, the seed having been previously sown in a bed of soil known to be free of smut. Since, however, transplanting is a laborious and expensive process, it is frequently desirable to treat the land or the drill in which the seed are sown, with sulfur, lime, or formalin. The fungicides mentioned have been used in the following manner: sulfur and air-slaked lime in the drill at the rate of 100 pounds of sulfur and 50 pounds of lime, or a solution of formalin containing 1 pound of the latter to 30 gallons of water.

Urocystis occulta (Wallr.) Reb. on rye (*Secale cereale*), is another species of this genus of special economic importance in the eastern and north central states.

CHAPTER XIV

PROTOBASIDIOMYCETES

I. RUST FUNGI

Uredinales

ARTHUR, J. C. Uredinales. North Amer. Flora **7**: 85–160. 1907.

ARTHUR, J. C. Cultures of Uredineæ; in 1899, Bot. Gaz. 1900; in 1900 and 1901, Journ. Myc. **8**: 1902; in 1902, Bot. Gaz. **35**: 1903; in 1904, Journ. Myc. **11**: 1905; in 1905, Journ. Myc. **12**: 1906.

BLACKMAN, V. H. On the Fertilization, Alternation of Generations, and General Cytology of the Uredineæ. Ann. Bot. **18**: 323–373. *pls. 21–24.* 1904.

CHRISTMAN, A. H. Alternation of Generations and the Morphology of the Sporeforms in the Rusts. Bot. Gaz. **44**: 81–101. *pl. 7.* 1907.

ERIKSSON, J., und HENNING, E. Die Getreideroste, ihre Geschichte u. Natur, sowie Massregeln gegen dieselben. 463 pp. *13 pls.* 1896. Stockholm.

FISCHER, E. Die Uredineen der Schweiz. 590 pp. *342 figs.* 1904. Bern.

KLEBAHN, H. Die Wirtswechselden Rostpilze. 447 pp. 1894. (Extensive bibliography, which see, especially for important papers by Klebahn and others.)

MCALPINE, D. The Rusts of Australia. Dept. Agl. Victoria. 349 pp. *55 pls.* 1906. (Also extensive bibliography.)

OLIVE, E. W. Sexual Cell Fusions and Vegetative Nuclear Divisions in the Rusts. Ann. Bot. **22**: 331–360. *pl. 22.* 1908.

PLOWRIGHT, C. B. A Monograph of the British Uredineæ and Ustilagineæ, with an Account of their Biology, etc. 347 pp. *8 pls.* 1889.

RICHARDS, H. M. On Some Points in the Development of Æcidia. Proc. Amer. Acad. Arts and Sci. **31**: 255–270. *pl. 1.* 1895.

SYDOW, P. Monographia Uredinearum. 1. Puccinia. 972 pp. 1904. Leipzig.

The Uredinales comprise about two thousand species, all of which are obligate parasites, and they represent perhaps the extreme of obligate parasitism. In no case has it been possible to grow these organisms upon artificial media or apart from the hosts beyond the stage of mere germination or of promycelial production. The host plants are predominantly the Spermatophyta, or seed plants, although a small number of these fungi are parasitic upon ferns. The host deformities vary in external appearance from almost inconspicuous discolorations to hypertrophies of considerable size, on the one hand, or to extensive witches' brooms

on the other. The production of spores, particularly the production of uredospores, is frequently in the nature of rust-like masses from which has been derived the common name applied to this family. Popularly the term *rust* has also been applied to certain leaf spot fungi, but this usage is ill advised.

This order appears to be somewhat closely related to the smuts; the presence of a promycelium (promycelial-like structure in the latter) giving, of course, the chief clue to this relationship. On the other hand, however, neglecting the feature of parasitism, there is a close relationship with the saprophytic Auriculariales, especially if we regard the teleutospore (promycelium, etc.) of the rusts as the all-essential spore form.

The mycelium is generally local. In special cases, however, it may penetrate through a considerable extent of the host, and it is also occasionally perennial. It is almost invariably intercellular, abundantly branched, rather closely septate, and provided with haustoria. The effect of the mycelium upon the host is not to kill directly. In fact, the mycelium may develop within a tissue to an enormous extent, yet the cells of the invaded tissue may remain completely functional; and death may result only when, after abundant fruiting of the fungus, the rupture of the epidermis is considerable, and doubtless the withdrawal of nutrients excessive. The spores which may be produced are of five general types, as given below.

Spore forms. (1) Spermatia (or pycnospores), in spermogonia (or pycnidia); (2) æcidiospores, in cup-like organs, æcidia; (3) uredospores, in pustules or sori; (4) teleutospores, in sori similar to the last; (5) sporidia, upon a promycelium developed directly from the teleutospore.

A species may include from one to five (all) of these types. The relations of these types one to another is definite and the number is ordinarily constant in the species.

The *spermatia* are minute spores produced in flask-shaped conceptacles (spermogonia or pycnidia). They are supposed to be now generally functionless. Many mycologists assume that they had originally the function of one sexual gamete. The spermogonia are commonly associated more or less closely with the æcidia, although they may be associated with other spore types.

The *æcidia* are essentially cup-shaped bodies produced by the differentiation of a compact mass of hyphæ growing perpendicular to the surface of the host. The outer layer of this body generally becomes a wall or peridium, the inner hyphæ originating each, or each pair, a chain of one-celled spores separating at maturity. At first sterile cells alternate with the spore cells, but these practically disappear by the time the spores are mature. Infection by the æcidiospore commonly results in the production of uredospores, less frequently teleutospores, and in very few instances (so far as can be ascertained) another generation of æcidiospores. The peridium is variable, and four types corresponding to four form genera may be recognized: in some cases a peridium is (1) absent (Cæoma); when present it is (2) toothed, the body being truly cup-shaped (Æcidium), (3) fimbriate, the body being elongate (Rœstelia), or (4) irregularly split and broken (Peridermium).

The *uredospores*, produced ordinarily in masses or cushions (the sori), are hyaline, or generally yellow to dark brown, ovoidal or spheroidal spores borne generally upon pedicels, which are, however, usually deciduous. In a few genera the uredospores are produced in chains. The walls of these spores are frequently echinulate or warty, and there are from two to ten germ pores meridionally disposed. Germination may proceed immediately. The germ tube penetrates the host plant through the stomata, in general, and the uredosporic form may ordinarily produce repeated generations of uredospores, under favorable conditions. Later in the season, or sometimes under less favorable conditions for propagative reproduction, teleutospores are developed.

Teleutospores are ordinarily produced in sori more or less similar to the uredospores. The teleutospores are generally thick-walled resting spores, although in a few genera, or subdivisions of genera, they may germinate immediately. Germination consists in the production of a promycelium (basidium-like), which is generally divided into four cells, from each of which arises on a sterigma a small thin-walled spore, a sporidium (basidiospore).

The *sporidia* germinate promptly under favorable conditions and may immediately penetrate the host. The mycelium developed from this infection may give rise to æcidia and spermogonia, uredospores and teleutospores, teleutospores alone, etc.

Heterœcism. In this order of fungi there has been developed not only great diversity in form and character of spores, and in the relationships of these types one to another, but also a very definite relationship between the different spore types and the host plants. Where more than a single spore type is present a species may either complete its entire life cycle upon a single host, that is, produce all spore forms in its life cycle on one host, or it may require two plants for complete development (in a few cases three) in regular order. The former group of rust fungi are termed *autœcious* and the latter *heterœcious*. Autœcism is the rule among fungi generally. Heterœcism is better developed in rusts than in any other group of living organisms, and it is with one or two exceptions confined to the rusts, so far as the fungi are concerned. There are more than 150 cases of heterœcism which have been experimentally demonstrated in this order, and this number will be greatly increased as the experimental work proceeds. Upon such hosts as the grasses, sedges, rushes (Gramineæ, Cyperaceæ, Juncaceæ), and allied plants, the spore forms produced are quite generally the uredo and teleuto stages, or one or the other of these; and in general, so far as the experimental work has been carried, such fungi have other stages, at least an æcidial stage, upon some dicotyledonous host. Indeed, in only one group of cases (the species of Puccinia on Phalaris) is the æcidial stage produced on another monocotyledonous host. Again, in no case of heterœcism has the æcidiospore been found to be capable of infecting also the host upon which it is borne. Since the teleutospore germinates by the development of a promycelium and sporidia, and in no other manner, it is precluded that the teleutospore may infect directly the host upon which it is produced. The uredospores alone possess this capacity.

In general, it would seem that the period of incubation may vary from eight to twenty days during the growing season, for most of the species of rusts. The time, however, will vary in the same species under different climatic conditions.

The terminology of spore combinations. Based upon the association of spore forms, that is, upon the number and kind of spores present in a particular species, Schroeter has proposed certain very convenient type names as below. First, however, it should be stated

that the spermogonial, æcidial, uredo, and teleuto stages are respectively represented by O, I, II, III, and it is here unnecessary to consider the fifth or sporidial stage ; the types, then, are as follows :

Eu forms with all stages; or O, I, II, III present.
Brachy forms with æcidia omitted; or O, II, III present.
Opsis forms with uredo omitted; or O, I, III present.
Hemi forms with spermogonia and æcidia omitted ; or II, III present.
Micro forms with teleutospores only; or III present, germinating only after a resting period.
Lepto forms with teleutospores only; or III present, germinating immediately.

It is interesting to note that in the far North or in Alpine regions, as Fischer shows, the *micro* and *lepto* forms predominate. Æcidia occur alone in considerable number, and also *hemi* forms. Many *hemi* forms, particularly in such genera as Uromyces and Puccinia, have been insufficiently investigated, and will doubtless prove to be *eu* forms, mostly heterœcious, that is, *eu-hetero* forms.

No terms applicable alike to all genera having similar spore forms, based upon some common root and the prefixes above mentioned, expressing also heterœcism and autœcism, have been suggested. It seems desirable for many reasons to employ as this root the word *uredo*, and since it will be used in combination with these prefixes, there can scarcely be any confusion, although uredo is a form-genus name. With this nomenclature a form which is eu-heterœcious will be termed *euheterouredo*, and the other combinations will be made in an analogous manner.

II. FAMILIES AND GENERA

According to Fischer the order may be most conveniently subdivided into four families, and the characters employed as a basis of this system of classification are for the most part those of the teleutospores.[1]

[1] Arthur has proposed for the Uredinales an entirely new system of classification (Résultats scientifiques du Congrés International de Botanique, Vienne, 1905, pp. 331–348). By this system many more genera would be constituted since, in addition to the usual characters, the completeness of the life cycle with respect to the four main stages is made generically diagnostic. He has also introduced the terms *pycnium*, *æcium*, *uredinium*, and *telium* in substitution for spermogonial, æcidial, uredo, and teleuto stages.

1. **Pucciniaceæ.** The teleutospores usually consist of a single cell or a vertical row, sometimes, however, united into the form of a relatively small head. The spores are borne on a simple or compound pedicel. The uredospores are single, on hyaline, deciduous pedicels. The æcidia are generally provided with a well-developed peridium. The genera here considered are Uromyces, Puccinia, Gymnosporangium, Gymnoconia, Phragmidium.

2. **Cronartiaceæ.** The teleutospores are without pedicels, and they originate in chains, or series, more or less free at maturity, or united into complex bodies. Chrysomyxa and Cronartium are the important genera.

3. **Coleosporiaceæ.** The teleutospores are united into a layer generally wax-like in texture, and orange-red in color. The spores are generally without pedicels, at first unicellular, but soon dividing into four cells, that is, to form the promycelium within the spore, each cell of which, therefore, produces a sterigma and basidiospore. The genus Coleosporium includes the more important species.

4. **Melampsoraceæ.** The teleutospores form a closely adherent crust-like layer, each cell of which germinates by a typical promycelium. The uredospores are borne singly, and the æcidia are with or without peridia. Melampsora is the chief genus.

The genera above mentioned may be briefly described as follows :

Uromyces. The teleutospores are unicellular with a terminal germ pore ; the uredospores are generally provided with many evident germ pores ; the æcidia are provided with peridia, the æcidiospores are without germ pores, and the spermogonia are spherical with minute circular ostiola.

Puccinia. This genus is similar to Uromyces except that the teleutospores are two celled. Unicellular teleutospores may also occur in some species.

Gymnosporangium. The teleutospores are commonly two celled, exceptionally three or four in a row. They are borne in pustules ; and, at maturity, owing to the development of substances resulting partially from the gelatinization of the long pedicels, they are pushed out into jelly-like masses, sometimes horn-like in form. The spores are often provided with several germ pores arising near the side wall, though apical germ pores may be present. There are no uredospores, and the æcidia (rœstelia) are often

jug-shaped or cylindrical, with thick-walled peridia. The æcidiospores are highly colored, and possess numerous germ pores. They are invariably accompanied by flask-shaped spermogonia.

Gymnoconia. This genus resembles Puccinia in the general characters of the teleutospore, and no uredospores are present. The most abundant spore form is that of the cæoma stage. The latter is an æcidium without a peridium, the spores being borne in chains; and in this case the spores are generally highly colored, orange to orange-yellow. The spermogonia are numerous, spherical, and very simple in form.

Phragmidium. The teleutospores are made up of three or more cells in a row borne upon a persistent pedicel. Uredospores are present, and these are borne in pustules bordered by paraphyses; each spore possesses several germ pores. The æcidia are also of the cæoma type, but here there is an outer border of unicellular, curved paraphyses. The spermogonia are flat or discoidal. Species of this genus occur only upon Rosaceæ.

Chrysomyxa forms a teleutosporic cushion, the cells of which are closely adherent. These spores germinate immediately by the production of a promycelium. The uredospores are borne in chains, as are also the æcidiospores, the two kinds being more or less similar. The æcidia, however, are provided with well-developed peridia.

Cronartium is characterized by teleutospores united into a cylindrical column, each spore germinating immediately by the production of a promycelium from near the apex. The uredospores are borne singly on pedicels within a semispherical body possessing a differentiated peridium. This latter structure is provided with a small terminal pore or mouth.

Coleosporium. In this genus the teleutospores are closely adherent, with a rounded, thickened, gelatinizing apex. The sterigmata are long, and the sporidia large, ovate, and flattened. The spore, at first a single cell, divides to produce a series of four inner promycelial cells.

Melampsora. The teleutospores are generally unicellular and closely united into indefinite crusts. The uredospores are borne singly, often interspersed with paraphyses. The æcidia are of the cæoma type, and paraphyses are occasionally present.

III. SYNOPSIS OF SPECIES

Arranging the species here discussed, together with a few others as examples, in groups according to the spore forms and heterœcism or autœcism, we have the following:

Euautouredo (Stages O, I, II, III)

	Hosts
Uromyces appendiculatus (Pers.) Lév.	Phaseolus vulgaris (beans) (also species of Dolichos and Lablab.)
Uromyces Trifolii (Hedw.) Lév.	Trifolium hybridum, T. incarnatum, T. pratense, T. repens, etc. (various clovers)
Uromyces Betæ (Pers.) Tul.	Beta vulgaris (wild and cultivated beet)
Puccinia Asparagi De C.	Asparagus officinalis (asparagus), etc.
Puccinia Helianthi Schw.	Helianthus annuus (sunflower), etc.
Puccinia Violæ (Schum.) De C.	Viola spp. (violets)
Puccinia Menthæ Pers.	Certain Labiatæ (mints)
Gymnoconia Peckiana (Howe) Tranz.	Rubus occidentalis (blackberry), etc.
Phragmidium subcorticium (Schrank) Wint.	Rosa spp. (various roses)

Euheterouredo (Stages O, I, II, III)

	Hosts O, I	Hosts II, III
Uromyces Pisi (Pers.) De Bary.	Euphorbia Cyparissias	Pisum sativum (pea) Lathyrus pratensis, etc.
Puccinia graminis Pers.	Berberis vulgaris (barberry)	Avena sativa (oats)
	Berberis Lycium	Hordeum vulgare (barley)
	Berberis Aquifolium	Secale cereale (rye) Triticum vulgare (wheat)
Puccinia Sorghi Schw.	Oxalis cymosa (oxalis)	Zea mays (Indian corn)
Puccinia Phlei-pratensis Eriks. & Henn.		Phleum pratense (timothy), etc.
Puccinia rubigo-vera De C.	Boraginaceæ	Triticum spp., Avena sativa, etc.
Puccinia Pruni-spinosæ Pers.	Hepatica acutiloba (hepatica)	Prunus spp. (plum, peach)

Chrysomyxa Rhododendri (De C.) De Bary	Picea excelsa (Norway spruce)	Rhododendron ferrugineum R. hirsutum
Cronartium Ribicola Fisch. de Waldh.	Pinus strobus (white pine)	Ribes spp. (currant, gooseberry)
Coleosporium Senecionis Pers.	Pinus sylvestris (Scotch pine)	Senecio vulgaris S. sylvaticus S. viscosus, etc.
Melampsora tremulæ Tul.	Pinus sylvestris (Scotch pine)	Populus tremula (poplar)

Opsiautouredo (Stages O, I, III)

	Hosts
Puccinia Tragopogi Pers.	Tragopogon spp. (salsify)

Opsiheterouredo (Stages O, I, III)

	Hosts O, I	Hosts III
Gymnosporangium macropus Lk.	Pyrus Malus (apple)	Juniperus virginiana (red cedar)
	Pyrus coronaria (wild crab)	J. virginiana (red cedar)
Gymnosporangium globosum Farl.	Pyrus Malus (apple)	J. virginiana (red cedar)
	Pyrus communis (pear)	J. virginiana (red cedar)
	Pyrus americana	J. virginiana (red cedar)
	Cydonia vulgaris (quince)	J. virginiana (red cedar)
Gymnosporangium Sabinæ (Dicks.) Wint.	Pyrus communis (pear)	J. Sabina
Gymnosporangium clavariæforme (Jacq.) Rees	Cratægus tomentosa	J. communis (common Juniper)

Brachyautouredo (Stages O, II, III)

	Hosts
Puccinia Hieracii (Schum.) Mart. .	Hieracium spp.
Puccinia suaveolens (Pers.) Rostr. .	Cirsium arvense (Canada thistle)

Hemiuredo (Stages II, III)

	Hosts
Uromyces Caryophyllinus (Schrank) Wint.	Dianthus Caryophyllus (carnation), etc.
Uromyces scutellatus (Schr.) Wint.	Euphorbia spp. (spurges)

Uromyces Rumicis (Schum.) Wint.	Rumex spp. (sorrels)
Hemileia vastatrix Berk. & Br. . .	Coffea arabica (coffee)
Puccinia Chrysanthemi Roze. . .	Chrysanthemum spp.
Puccinia Polygoni Pers.	Polygonum spp.
Puccinia Allii De C.	Allium Cepa (onion)

Microuredo (Stage III)

Uromyces Solidaginis (Somm.) Niessl.	Solidago spp. (goldenrod)
Puccinia Ribis De C.	Ribes spp. (currant, gooseberry)
Puccinia fusca Relhan.	Anemone nemorosa, etc.

Leptouredo (Stage III)

Puccinia malvacearum Mont. . .	Althæa rosea (hollyhock), etc.
Puccinia Xanthii Schw.	Xanthium spp. (cocklebur)

(Stages O, III)

Uromyces tepperianus Sacc. . . .	Acacia spp.

(Stages O, I)

Æcidium elatinum Alb. & Schw. .	Abies spp. (firs)
Æcidium Grossulariæ Schum. . .	Ribes spp. (currant, gooseberry)
Peridermium Engelmannii Thüm.	Pinus Engelmannii

(Stage II)

Uredo Fici Cact.	Ficus carica (fig)
Uredo Gossypii Sager.	Gossypium hirsutum (cotton), etc.

During the past few years considerable activity has been manifest in the study of the cytology and possible fertilization processes in the Uredinales. It had been known since the studies of Sappin-Trouffy and Dangeard that the binucleate condition of the teleutospore and of the mycelium preceding it leads finally to a fusion of these two nuclei preceding the development of the promycelium. The recent studies have been directed primarily toward a knowledge of the origin of this binucleate condition. Blackman in some extensive studies of a cæoma stage, in particular, demonstrated what he believed to be a fusion phenomenon in the following manner: During the early development of this stage numerous gametic branches arise. These come in contact in pairs, the older and

larger branch cutting off an apical cell. The smaller gamete in time loses its nucleus by migration through a pore into the larger gamete, and the cells thus provided with two nuclei become each properly the basal cell of one of the chains of spores which arise in this type, corresponding to the æcidium, each spore of which

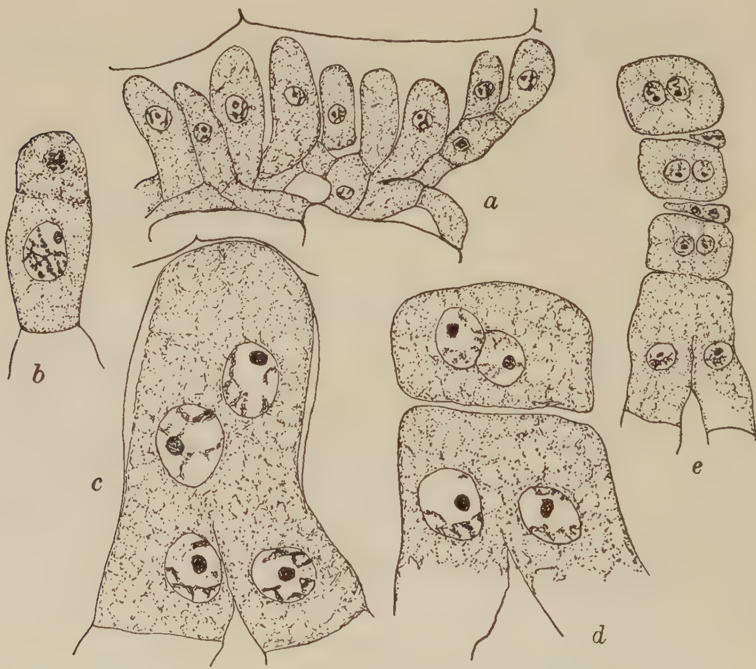


FIG. 194. *PHRAGMIDIUM SPECIOSUM:* DEVELOPMENT OF ÆCIDIOSPORES (After Christman)

a, progametes; *b*, gamete and sterile cell; *c*, after gametic fusion and nuclear division; *d* and *e*, spore production

possesses paired nuclei. He would also homologize the apical cell of the larger gamete with the trichogyne of certain lower plants, and would assume that in the phylogeny of these plants the spermatia were functionally in connection with this organ. The work of Christman and Olive on this and other rust fungi in part confirm Blackman's results. They are also able to identify the gametes, but the communication between these two adjacent cells is generally,

however, effected by a dissolution of the upper portion of the cell walls in contact, thus securing a union of two cells. From these united cells, with two nuclei, as a basal structure arise the chain of spores as before. The evidence offered seems to thoroughly explain the origin of the binucleate condition. While there are many exceptions which might be noted, there is in general, in the case of a species showing all spore types, the following nuclear life history. The mycelium which produces the spermogonia and the æcidium is uninucleate. There is a fusion of cells in the æcidium (where such organ is present) and the æcidiospores are binucleate. The mycelium which produces the uredospores and the teleutospores is binucleate, and these spores are themselves binucleate (in this type). Fusion of the nuclei results at about the time of germination of the teleutospore, so that the sporidia are uninucleate. It is, however, unnecessary here to enter into a more detailed discussion of these phenomena.

IV. CLOVER RUST

Uromyces Trifolii (Hedw.) Lév.

HOWELL, J. K. The Clover Rust. Cornell Agl. Exp. Sta. Bullt. **24**: 129–139. 1890.
PAMMEL, L. H. Clover Rust. Iowa Agl. Exp. Sta. Bullt. **13**: 51–55. 1891.

Habitat relations. The clover rust is ordinarily a common disease of various species of Trifolium. It causes a disease of the clovers more serious in many instances than that produced by Pseudopeziza, already mentioned. The Uromyces is cosmopolitan, and the more susceptible hosts are important forage plants. Among the clovers the following species are frequently infested : red clover (*Trifolium pratense*), hybrid clover (*Trifolium hybridum*), white clover (*Trifolium repens*), and crimson clover (*Trifolium incarnatum*). The prevalence of the disease apparently varies greatly with the season, and is to a considerable extent determined by the spring conditions. We have, however, no very accurate knowledge of the climatic relations of this fungus.

This fungus is taken as a type of an autœcious member of the genus, as it may have all stages on the same host plant. The various stages commonly occur upon *Trifolium repens* and also

upon *Trifolium incarnatum* L., much less frequently, however, upon some of the other species mentioned. In general, the spermogonial and æcidial stages are not commonly found upon the red clover, the host upon which the other stages are perhaps most frequent. Nevertheless, the reported absence of æcidial stages upon this host in certain regions may be due to the fact that careful examinations have not been made at the proper season.

FIG. 195. *UROMYCES TRIFOLII:* CLOVER RUST

The fungus. The mycelium corresponds very closely to that described as generally characteristic of the whole order. It is considered to be local. The spermogonia and æcidia generally appear during very early spring or at almost any time during open winter. They occur upon the under surfaces of the leaves and on the petioles. The æcidiospores (14–23 μ in diameter) germinate readily in water, and under favorable conditions infection in the greenhouse or in the open may be secured, with the production of uredosori within two weeks. The uredospores, as shown in Fig. 195, *d*, measure about 22–26 × 18–20 μ. These spores also germinate readily, and repeated crops of the uredospores may be produced, possibly in some cases extending into the winter, and even carrying the fungus through the year. Teleutospores are produced, however, and these may occur in sori with uredospores, or in independent sori, as the season

advances. These spores are 20–35 × 15–22 μ, and a spore germinates by the production of the characteristic promycelium, divided ordinarily into four cells, each producing its sporidium. The germination of the teleutospore would seem to take place ordinarily several weeks prior to the appearance of the spermogonium and æcidium, both of which arise only from teleutosporic infection. Sydow accepts the separation of the rust of clovers into two species. The absence of stages O, I, also the more numerous germpores in II, distinguish the form on red clover from that on white.

FIG. 196. *Uromyces appendiculatus:* Rust of Beans. (Photograph by H. H. Whetzel)

As a rule, control measures seem to be unnecessary; at any rate no practical preventive methods are known.

V. RUST OF BEANS

Uromyces appendiculatus (Pers.) Lév.

DE BARY, A. Recherches sur le développement de quelques champignons parasites. Ann. d. Sci. nat. Bot. (Sér. 4) **20**: 68–99. 1863.

WHETZEL, H. H. Bean Rust. Cornell Agl. Exp. Sta. Bullt. **239**: 298–299. *figs. 113–115.* 1906.

This fungus is widely distributed, occurring on the bean (*Phaseolus vulgaris*) and other related species. It is also reported in southern latitudes on relatives of the cowpea, such as *Dolichos ornatus*,

Lablab vulgaris, *Vigna marginata*, etc. The fungus commonly appears late in the season, and it is often destructive to foliage, causing early maturity and lessened production of the beans. There is great difference in susceptibility of varieties both among dwarf and pole sorts. Moreover, the fungus is harbored by the old leaves and vines. Burning these would reduce the quantity another year. The effect of turning under affected parts does not seem to have been tested. Selection of resistant varieties would seem to be possible for each locality. The spermogonia and æcidia are very light in color. The æcidiospores are colorless and polyhedral, $17-32 \times 14-23\,\mu$; the obovate, minutely echinulate uredospores, which are $24-33 \times 16-20\,\mu$, occur in rather minute sori; and the teleutospores are broadly elliptical, measuring $26-35 \times 20-26\,\mu$, and each spore is provided with a large, terminal papilla.

VI. RUST OF VETCH AND GARDEN PEA

Uromyces Pisi (Pers.) De Bary

De Bary, A. Recherches sur le développement de quelques champignons parasites. Ann. d. Sci. nat. Bot. (Sér. 4) **20**: 68–99. 1863.
Klebahn, H. Die wirtswechselden Rostpilze, *l.c.*, p. 330.

In the United States this species is not so prevalent as the preceding species. It shows, however, an interesting heterœcism. The pycnidia and æcidia occur on *Euphorbia Cyparissias*, while the uredospores and teleutospores are found upon *Lathyrus pratensis*, *Vicia cracca*, *Pisum sativum*, and *Pisum arvense*. In addition, a number of other hosts have been given for stages II and III. In this rust the æcidia and spermogonia are together irregularly distributed on the under surfaces of the leaves. The æcidia are numerous, with deeply cleft peridia, the cells of which have a very slight lumen. The æcidiospores are more or less isodiametric, and from 18 to 22 μ in diameter. The spore wall is decorated with fine wart-like projections. The uredosori are small, pulverulent, and distributed over the leaf. The uredospores are more or less spherical, and measure $21-25\,\mu$. The wall is thick and the 4–5 germ pores are evident. The teleutospores are obovate, with short, hyaline stalks. The wall is uniformly thickened and beset with fine warts, except at the apex, where there is a conspicuous, flat papilla.

VII. BEET RUST

Uromyces Betæ (Pers.) Tul.

KÜHN, J. Der Rost der Runkelrübenblätter, *Uromyces Betæ*. Bot. Zeitg. **27**: 540–544. 1869.
McALPINE, D. The Rusts of Australia, *l. c.*, *Uromyces betæ* (Pers). Kühn., 100–101. *pl. 17, figs. 148–149; pl. 43, fig. 316; pl. H.*

The spermogonia occur in small, yellowish groups, and the æcidia in similarly colored but somewhat larger spots, within which they may be arranged in circular or regular form. The æcidia are saucer-shaped and white, the æcidiospores more or less isodiametric, 17–36 μ in diameter, with orange-colored contents. Both the uredo and the teleuto stages occur in sori irregularly distributed over the surfaces of the leaf, often circularly disposed. The uredospores are mostly obovate, $21–24 \times 35\,\mu$. The walls are provided with somewhat distant echinulations and two opposite germ pores. The teleutospores are similarly obovate, $18–24 \times 25–32\,\mu$. The wall is scarcely thicker at the apex, with an apical germ pore, and a very distinct papilla of the same diameter as the germ pore. The pedicel is short and persistent. This fungus is prevalent in Australia, and it is not uncommon in Europe; but in the United States it appears only to have been observed in California. This species is found on cultivated beets (*Beta vulgaris*), also on wild species of this genus. According to the observations of Kühn the mycelium may be biennial in the host, forming æcidia practically throughout the year.

VIII. CARNATION RUST

Uromyces Caryophyllinus (Schrank) Wint.

ATKINSON, GEORGE F. Carnation Diseases. Amer. Florist **8**: 720–728. *figs. 1–33.* 1893.
STEWART, F. C. Combating Carnation Rust. N. Y. (Geneva) Agl. Exp. Sta. Rept. **15**: 461–495. 1895. (Also Bullt. **100**.)
STUART, WM. Some Studies upon Carnation Rust. Vermont Agl. Exp. Sta. Rept. **8**: 115–118. 1894.

Occurrence and effects. The fungus causing carnation rust was recognized in Europe more than a century ago, and it was properly named during the first half of the nineteenth century. It has long been recognized as a common disease of the carnation (*Dianthus*

Caryophyllus), and it occurs also upon other species of this genus, and upon some other related genera. Prior to 1890 it had not been noted in the United States, and it is doubtful if it was previously common. Since that time, however, it has rapidly spread throughout the regions where carnations are grown either under glass or in the open. For a few years after its abundant appearance in this country it threatened to cause a panic in carnation growing, and florists' magazines and papers devoted much space to a discussion of the disease, methods of control, susceptibility of varieties, etc.

FIG. 197. CARNATION RUST

It is now permanently established as one of the regularly anticipated diseases of the carnation, but there is no fear that its presence in any way jeopardizes carnation growing as an industry, at least so far as the best growers are concerned.

Host resistance. Since the appearance of this pest there has been opportunity for selection, so that resistant varieties might be secured, or at least so that the more susceptible sorts might be discarded, particularly when more or less similar varieties may be grown which are less sensitive. Perhaps no commercial variety of this plant has proved more susceptible to the rust than the Scott. The susceptibility of this variety seemed to be intensified the longer it was in the trade. The Jubilee (scarlet) and Flora Hill (white) have also proved susceptible, and these have

been to a very considerable extent discarded by growers who cannot handle the plant so as to prevent rust. On the other hand, varieties like the Enchantress (daybreak pink) and Lawson (pink) have under a variety of conditions demonstrated a high degree of resistance. Nevertheless, the conditions under which the plants are grown affects to a considerable extent the amount of the rust. Of two growers using cuttings from the same stock with different regard for sanitation and different methods of cultivation, the one may find the rust abundant in his houses, and the other may be able to grow plants practically free from it. It is certain that poor ventilation and conditions permitting the deposit or retention of drops of water upon the surfaces of the leaves is more conducive to the spread of the fungus, but its approximate relations to environmental factors have not been determined.

The fungus. The life history of this fungus is incompletely known. The uredosporic stage is the common method of propagation, but the teleutosporic stage may also be found under the conditions of greenhouse or garden. The uredospores are more or less spherical or ellipsoidal in form, ordinarily varying from $24–35 \times 21–26\,\mu$. The cell wall is thick and sparsely beset with minute spines. The uredosporic pustules are pulverulent, light chestnut brown in color, and may be found upon leaves or stems. The teleutospores are not dissimilar in form to the uredospores, and are commonly ellipsoidal, varying from $20–35 \times 18–25\,\mu$. The rather uniformly thickened chestnut brown membrane is marked by minute wart-like markings best seen in the dry condition. The spores possess terminal germ pores marked by a papillate, hyaline covering. The pedicels are short and colorless. The uredospores germinate readily in water, and the experiments made by Stewart indicate that they are unusually resistant to many fungicides and toxic agents. A solution of 1–500 copper sulfate was required to give inhibition of germination, and a still stronger solution to entirely prevent germination. On the other hand, potassium sulfide 1–1000 prevented germination, and even weaker solutions inhibited considerably this process.

It would appear that the mycelium is not greatly localized in the host, but no accurate determination of this point can be cited. Furthermore, few inoculation experiments have been made

in order to determine the possibility of spreading the disease to vigorous adult plants. Observation would indicate that adult plants may be affected, and consequently that the disease may be spread rapidly during the growing season. In fact, it is only upon this basis that the rapid spread of the fungus can be accounted for. Yet there is very little experimental data upon which to rely for confirmation of this statement.

Control. Three methods of control have been considered and, when necessary, practiced, and these in addition to a maintenance of the best general conditions of the environment with respect to sanitation. In the first place, resistant varieties should be grown as far as possible. Secondly, it is desirable, where the rust abounds, or where rust-susceptible varieties must be grown, to have simple V-shaped wire mesh supports placed between the rows in order to hold the foliage away from the moist soil, and also to permit of watering without constant wetting of the leaf surfaces. Thirdly, it may be necessary to employ fungicides when other methods fail. In such cases the plants may be sprayed once each week with a solution of copper sulfate about 1-500 (1 lb. copper sulfate to 12–15 gallons of water), or with a solution of potassium sulfide 1 ounce to 1 gallon.

IX. UROMYCES: OTHER SPECIES

Uromyces scutellatus (Schr.) Wint. apparently occurs as a very common parasite of a large number of species of Euphorbia. The species is ordinarily broken up into different forms, which vary very slightly one from another in general appearance and considerably in extreme size, the uredospores being $17–35 \times 14–23\,\mu$, and the teleutospores $20–38 \times 16–25\,\mu$. Whether this fungus is, in any of its forms, a euheterouredo, or invariably a hemiuredo, as it appears to be, is not definitely determined.

Uromyces Rumicis (Schum) Wint. This species is found on many members of the genus Rumex. It appears to be a hemiuredo.

Uromyces Solidaginis (Somm.) Niessl. This is commonly considered to be a microuredo and occurs upon several species of Solidago.

X. ASPARAGUS RUST

Puccinia Asparagi De C.

HALSTED, B. D. The Asparagus Rust; Its Treatment and Natural Enemies. N. J. Agl. Exp. Sta. Bullt. **129**: 1–20. *pl. 1–2.* 1898.
HALSTED, B. D. Experiments with Asparagus Rust. N. J. Agl. Exp. Sta. Rept. **11**: 343–347. 1898.
SIRRINE, F. A. Spraying for Asparagus Rust. N. Y. Agl. Exp. Sta. Bullt. **188**: 122–166. 1900.
SMITH, RALPH E. The Water-Relation of Puccinia Asparagi. Bot. Gaz. **38**: 19–43. *figs. 1–21.* 1904.
SMITH, RALPH E. Further Experience in Asparagus Rust Control. Calif. Agl. Exp. Sta. Bullt. **172**: 1–22. 1906.
SMITH, RALPH E. Asparagus and Asparagus Rust in California. Calif. Agl. Exp. Sta. Bullt. **165**: 1–95. *figs. 1–45.* 1905.
STONE, G. E., and SMITH, R. E. The Asparagus Rust in Massachusetts. Mass. (Hatch) Agl. Exp. Sta. Bullt. **61**: 1–20. 1899.

FIG. 198. *PUCCINIA ASPARAGI:* RUST OF ASPARAGUS

Distribution and general effects. The fungus causing asparagus rust was described a century ago, and the effects of this fungus upon the asparagus plant have been known perhaps almost as long by growers in Europe. It has been, however, in general of no great consequence as an asparagus disease; but upon making its appearance in America, somewhat more than twelve years ago, this rust began, under our conditions, immediately to assume an unexpected importance. In a brief space of time the asparagus-growing interests of the country were seriously threatened. According to Halsted, who followed closely its early spread in this country, it became in 1896 a serious pest in New Jersey, Delaware,

Long Island, and parts of New England. In succeeding years it became more serious in those sections, and spread also rapidly southward and westward. It has, however, varied greatly in destructiveness in the eastern states from year to year, but on the whole the asparagus industry suffered such a check that a much more complete study has been made of methods of culture, of direct means of control, and of varietal resistance. As a result, in the East the asparagus interests have been gradually adapted to the new conditions, and it is not likely that the former epidemics have left any very serious impression upon this product as grown for immediate marketing.

In 1901 the rust seems to have been of the first serious consequence in southern California, spreading northward, and doing the greatest damage up to about 1905, since which time the energetic control measures suggested by Smith have been effective with the best growers in many localities.

Climatological relations. It has been demonstrated that the prevalence of asparagus rust in most localities bears a very definite relation to climatological and other conditions. When the air remains dry throughout the summer, rust is very largely prevented. Occasional rains with intervening periods of low humidity do not constitute favorable conditions for the fungus. A heavy formation of dew is almost inevitably requisite to the abundance and spread of the disease. This latter is of much practical importance in California, and referring to the conditions in that state, Smith says, "*The amount of rust varies directly and exactly with the amount of dew, and so long as there is little or no dew, there can be no rust.*"

Again, on light soil which has a tendency to dry out during the growing season, rust is prevailingly worse than on land where the plant secures the amount of moisture needed by the roots. The greater susceptibility on such lands has been attributed to the reduced vigor of the host plant, but here also a dew relation may often be a possible factor. Nevertheless, good cultivation is favorable to the host plant, as innumerable experiments have demonstrated. It should further be noted that the asparagus under half shade is commonly free from rust.

Host plants. Among the varieties of asparagus commonly grown in the United States, the Palmetto has proved most resistant, this

resistance being particularly noticeable when the varieties are grown side by side for a period of years. The final effect of the rust upon the plant from year to year is a determining factor in adaptability. Sirrine was unable to confirm the observations as to the high resistance of the Palmetto as grown on Long Island, but it is suggested that a weaker strain is there in use. Conover's Colossal and the various forms related to this, or the selections from it, are types of the more susceptible sorts. These, moreover, are the varieties upon which the canning industry depends. The fungus also occurs on some wild species of asparagus such as *Asparagus capsicus* and *Asparagus maritimus*.

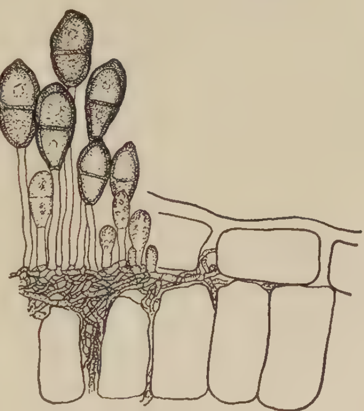


FIG. 199. *Puccinia Asparagi*: Teleutosporic Sorus

The spore forms. No important distortions are made upon the host by different stages of this fungus. All spore forms are produced on stems and twigs (Fig. 198), and the uredo and teleuto stages occur also on the leaf-like branches. The æcidial stage may appear at almost any point in the United States with a growing season no shorter than that of northern New Jersey. The æcidia appear in rather long, light green, cushion-like areas. They are short-cylindrical, with a white peridium, and the spores appear orange colored from the contents; the wall, however, is hyaline and granulose. The spores measure 15–18 μ in diameter. They may germinate immediately, and when dry, some at least retain the capacity for germination throughout several weeks. Penetration of the host plant is apparently through the stomata. The spermogonia appear in small yellow clusters.

The uredo or red rust stage appears in early summer, or shortly after the æcidial stage, at first in scattered, deep brown sori, but afterwards the latter may be confluent. The uredospores are yellowish brown, with thick walls, fine yellow markings, and provided

with four germ pores. They measure 21–24 μ. They are produced in such abundance as to be dusted in quantity upon any passing object or taken in clouds by the wind for some distance. They are unquestionably the chief means of distributing the disease during the growing season. It has been found (Smith) that their vitality upon drying is not retained for more than a few months.

The black rust stage appears later in the season, apparently as the conditions for uredosporic formation become unfavorable. The sori are black-brown, and while for a time protected by the epidermis, they are finally exposed. The teleutospores are elliptical, slightly constricted, as a rule, and measure 30–60 × 21–28 μ. The wall is thick at the apex, and the pedicels very long. These spores show a more or less persistent attachment to the host. Unicellular teleutospores also occur. They have been germinated towards the middle or end of winter, with the characteristic promycelium and sporidia. It is believed that the general infection in cultivated fields each season results from æcidiospores produced on wild or escaped plants, and not directly from the germination of teleutospores which have remained in or about the soil.

Control. The numerous attempts which have been made to control the asparagus rust by means of Bordeaux mixture have been more or less unsuccessful. Nevertheless, Sirrine, in experiments on Long Island, and later others have used to advantage a Bordeaux prepared with resin. The mixture which may be recommended is as follows:

Bordeaux mixture, 5–5–40 formula, 40 gals.
Resin mixture, 2 gals., diluted to 10 gals.
The resin preparation consists of resin, 5 lbs.; potash lye, 1 lb.; fish oil, 1 pt.; and water, 5 gals.

In California it has been found that under certain climatic conditions thorough spraying with sulfur, either as dust or liquid, is an efficient preventive, the prevention resulting from the fumes. In any case, however, where control consists in the use of sprays, provision should be made for the best circulation of air possible, that is, the field should be as free from obstructions around the border, and the rows should be a sufficient distance apart so as not to make the conditions any more favorable than possible for high moisture content of the air. Thorough cultivation should be

given, and requisite irrigation is desirable when there is a tendency for drying out to affect the health of the plant during the summer. It would appear, however, that the best method of controlling the fungus is by the selection of resistant sorts. Since the Palmetto variety has shown itself fairly resistant in the East, it is probable that other sorts may be obtained which will possess some of the desirable qualities of the Conover, with the resistance of the Palmetto. So far as I am aware, no extensive report has been made upon the resistance of European varieties under our conditions.

XI. VIOLET RUST

Puccinia Violæ (Schum.) De C.

ARTHUR, J. C., and HOLWAY, E. W. D. Violet Rusts of North America. Minn. Bot. Studies Bullt. (Ser.) **2**: 631–641. 1901.

This species of violet rust is parasitic on about sixty different hosts in the genus Viola throughout North America and parts of South America, also Europe and Asia. The spermogonia and æcidia occur early in the season in light brown spots scattered over leaves and stalks. The æcidiospores are ovoidal, $16–24 \times 10–18\,\mu$. The uredospores and teleutospores follow in succession, both of these on the under surfaces of the leaves, producing no definite spots; yet a large number of sori may become confluent so as to present the appearance of dark brown areas. The fungus is not of much consequence from an economic point of view in relation to violet culture, but it is, nevertheless, the most common of the five (assuming the validity of some species) violet rusts.

XII. MINT RUST

Puccinia Menthæ Pers.

This is a species apparently well distributed throughout a large part of the world on about thirty-five members of the mint family. The fungus is closely related to a number of other species whose host plants are also certain mints. In fact, more than thirty species of rusts have been described upon the various mints, and the studies that have thus far been made upon these indicate an interesting evolution of the parasitic forms. The species referred to, however,

is one of the most common, yet it may not be considered of any special economic importance. The æcidiospores are almost twice as long as broad, $40 \times 17–26\ \mu$. The uredospores are subspherical, and the teleutospores are conspicuous by their long, hyaline, and relatively thick pedicels, papillate apex, red-brown color, and verrucose outer wall.

FIG. 200. ÆCIDIAL STAGE OF THE GRAIN RUST ON BARBERRY

XIII. BLACK RUST OF GRAIN

Puccinia graminis Pers.

BOLLEY, H. L., and PRITCHARD, F. J. Rust Problems. N. Dak. Agl. Exp. Sta. Bullt. **68**: 607–672. *figs. 1–30.* 1906.

CARLETON, M. A. Cereal Rusts of the United States. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **16**: 1–73. *pls. 1–4.* 1899.

DE BARY, A. Neue Unters. über die Uredineen, insb. d. Entw. der Puccinia graminis u. d. Zusammenhang desselben mit Aecidium Berberidis. Monatsber. K. Akad. d. Univ. Berlin (1865): 15–49. *pl. 11.*

ERIKSSON, J. Neue Unters. über d. specialisirung Verbreitung u. Herkunft des Schwarzrostes (*Puccinia graminis* Pers.) Jahrb. f. wiss. Bot. **29**: 499–524. 1896.

ERIKSSON, J., und HENNING, E. Die Getreideroste, *l. c.*

MCALPINE, D. The Life-history of the Rust of Wheat. Dept. Agl. Victoria Bullt. **14**: 1891.

OLIVE, E. W. Rusts of Cereals. S. Dak. Agl. Exp. Sta. Bullt. **109**: 1–20. *figs. 1–5.* 1908.

WARD, H. MARSHALL. Illustrations of the Structure and Life-history of Puccinia graminis, the fungus causing the "Rust" of Wheat. Ann. Bot. **2**: 217–222. *pls. 11, 12.* 1888.

Probably the most important species of the rust family, both from an economic point of view and also from the point of view of the development of mycological research, is the common species, *Puccinia graminis*, upon cereals. It was upon this species that the classical researches of De Bary (1865 et seq.) were based, throwing light upon many phenomena of parasitism. In more recent times this species has served further as a means of developing a knowledge of biological and physiological forms, or specialized races. It has been the means, also, of showing the relation of the summer spore, or uredo stages, to the continual propagation of certain rust forms, and Eriksson's mycoplasm theory sought evidence in phenomena observed in this species.

FIG. 201. RUST OF OATS

Distribution and occurrence. It would appear that this fungus is distributed, in one or more of its numerous forms or races, throughout the world wherever certain grasses may be found. It is not in all regions the most common cereal rust, but in general it is so considered. The economic work upon rust fungi in such widely separated and important cereal-growing countries of the world as Australia, Russia, Western Europe, and the United States has been largely concerned with this species. It is therefore the fungus which is commonly known as rust of wheat, oats, barley, and other cereals and many grasses. It is not at all restricted by minor climatic conditions, and in the United States it is found in its various forms upon certain grasses from the moist Atlantic seaboard to the most arid portions of the Great Plains, and from the Gulf Coast to the Great Lakes. The annual losses throughout the world amount to a stupendous figure, often estimated to reach one hundred million dollars.

Host plants. It is scarcely possible to indicate all the various hosts upon which the species, in its various forms, has been reported. As mentioned above, however, it attacks all the more important cereals, — wheat, oats, rye, and barley, — together with ordinary grasses belonging to the same genera, in addition to such economic forms as species of Dactylis, Alopecurus, Agrostis, Poa, Phleum, Festuca, and numerous others.

The important forms or physiological races of this species which have been thus far well established through experimental study are as follows:

1. Secalis Eriks. & Henn. On *Secale cereale*, *Hordeum vulgare*, *Agropyrum repens*, *Elymus arenarius*, *Bromus secalinus*, and other hosts.

2. Avenæ Eriks. & Henn. Occurring on several species of Avena (including cultivated oats), *Agrostis scabra*, *Alopecurus pratensis*, *Dactylis glomerata*, and other grasses. Nevertheless, there is some disagreement about some of the hosts upon which this form has been reported.

3. Tritici Eriks. & Henn. On several species of Triticum (cultivated wheats), Hordeum, Agropyrum, and Elymus; also some other grasses.

4. Agrostis Eriks. On *Agrostis canina* and *Agrostis stolonifera*.

5. Airæ Eriks. & Henn.

6. Poæ Eriks. & Henn. on *Poa compressa*. This form, however, requires further study in order to be sure that it is not more properly one of those already indicated.

The fungus. This species is of the type euheterouredo. The chief alternate host throughout its usual range is the common barberry (*Berberis vulgaris*). The life history of the fungus may be only briefly outlined, beginning with its appearance upon the barberry in the form of the spermogonial and cluster-cup stages.

The mycelium is septate, considerably branched, and intercellular. It gives rise, however, to small, very slightly differentiated haustoria, which penetrate the cells. The mycelium is distributed, in the case of the barberry, throughout various parts of the leaf. It is, however, in every case localized in areas within a definite range of the point of infection. In the development of the spore stages there is the usual sequence. The spermogonial stage appears

first as small, flask-shaped bodies, shown in Fig. 202, breaking through the upper epidermis of the leaf. Somewhat later, and in the same spot, there appear on the under surface the æcidial

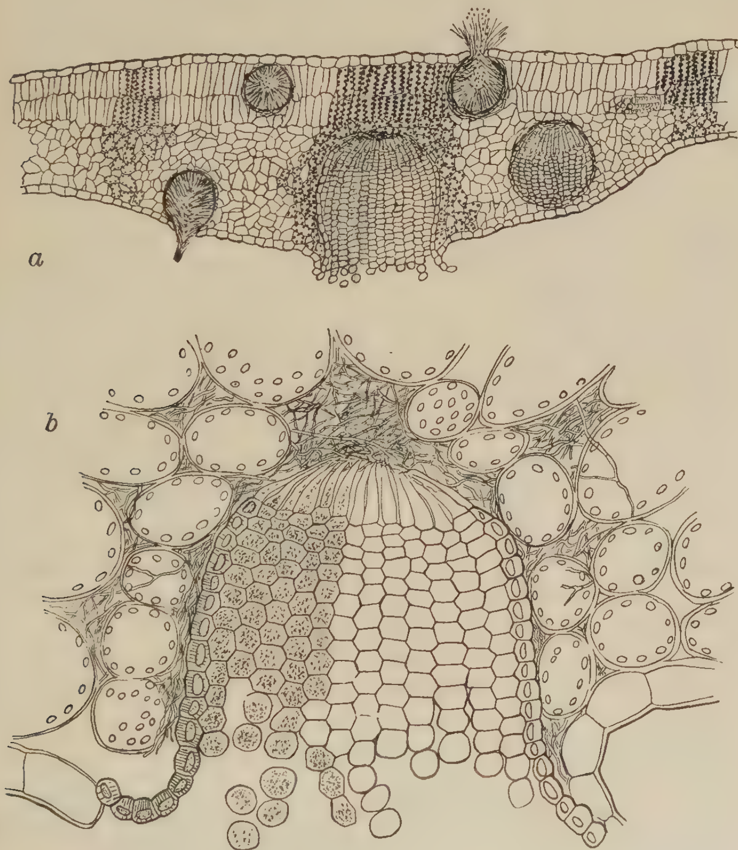


FIG. 202. *PUCCINIA GRAMINIS.* (After Ward)

a, section of barberry leaf showing spermogonia and æcidia; *b*, æcidium

stage, which breaks through the epidermis in somewhat similar manner. The spermogonium shows a very simple development, resulting by the gradual growth in extent of a small mass of filamentous hyphæ developing in an intercellular manner just beneath

the upper epidermis. At maturity the flask-shaped body consists of an indefinite wall, later giving rise to numerous filamentous branches within, most of which project inward toward the center, the majority bearing on their tips small rod-shaped or oval conidia. Other filamentous hyphæ emerge from the mouth of the pycnidium as hair-like processes. The hyphæ making up the pycnidium are all tinted yellow or orange in color, the coloring matter being first present in the protoplasm and later deposited in the cell walls. The spots in which first the pycnidia and later the æcidia are produced are pale yellowish to orange in color, and the leaf is sometimes considerably thickened.

The æcidia are organized in the mesophyll tissue near the lower epidermis. In general, each æcidium is differentiated and developed following the formation of a weft of filamentous hyphal elements. According to Richards there is first formed at the base of the hyphal mass a well-differentiated short, thickened hypha. By the division of this hypha there arise numerous fertile branches, or young conidiophores, each of which originates a chain of spores. Every alternate cell in the chain becomes a perfect spore; the others are small and temporary, remaining for a time as wedge-like structures between the spores. The outer border, or inclosing layer, consisting of differentiated hyphæ, forms a definite peridium. Prior to the rupture of the epidermis, the fruit body has a more or less spherical form, and it consists merely of the sheath, or peridium, inclosing the numerous chains of spores. The increase in size of the spores breaks the peridium as well as the epidermis, and the æcidia appear superficially in the cluster-cup form (Fig. 202). The spores there exposed separate readily and are distributed. The æcidiospores are more or less spherical and vary from 14 to 26 μ in diameter. This spore germinates, and upon the different grass hosts it penetrates the stomata, producing the mycelium of the uredo stage.

The uredosori generally occupy linear areas, yet upon some hosts they may be in the form of small circular dots. They show a considerable amount of coloring matter when young, and when mature appear yellowish brown. They are ovate, $10–15 \times 20–35\,\mu$, with rather thick walls, the outer of which bears numerous echinulations or small spine-like appendages (Fig. 203, *a*). There are four

germ pores equatorially disposed and opposite. Upon many hosts the uredospores are produced throughout a very long season. They may appear upon grain or blue grass in the early spring before the æcidiospore may be developed in the same region. In many cases it is evident that the rust may be propagated from year to year by continuous generations of the uredospores. Again, it has been experimentally shown that uredospores may retain the power of

FIG. 203. *PUCCINIA GRAMINIS:* UREDOSPORES AND TELEUTOSPORES

germination for weeks. It is, therefore, generally possible to account for the appearance of rust, even in spring grain, at a distance from the alternate barberry host. In seeking to explain the infections in spring grain as due to the uredo stage from some neighboring grass stubble, it should be remembered that artificial inoculation experiments have shown a very definite restriction of hosts in the different physiological species. Some who have followed carefully outbreaks of rust in the grain fields, year after year in the Northwest, feel that the problem is not yet completely

solved. The rust may appear, or seem to appear, in constantly increasing amount in a field repeatedly grown to wheat, other conditions apparently remaining the same, yet it is hardly possible to assume that wintered uredospores would explain such cases.

The teleutosori are generally disposed in a linear manner on stems, leaves, and floral parts. They may arise, during the early part of the season, in the uredosorus, but as the plant matures, teleutospores alone are developed; thus the black rust form is that most evident at harvest time and later upon the stubble. In general, the spores are somewhat spindle-shaped, or somewhat broader at the apex, deep brown in color, with a persistent pedicel (Fig. 203, *b*). They measure $35\text{–}60 \times 12\text{–}22\,\mu$. One-celled spores are occasionally found. The teleutospores will not, as a rule, germinate with any degree of satisfaction until they have been exposed to outside conditions throughout a considerable portion of the winter. Germination has, however, been repeatedly followed, and in moist air the promycelium is typically four-celled, each producing upon a fairly long sterigma the single sporidium (Fig. 203, *b*).

XIV. RUST OF MAIZE

Puccinia Sorghi Schw.

ARTHUR, J. C. The Æcidium of Maize Rust. Bot. Gaz. **38**: 64–67. 1904.

It is generally supposed that this fungus is a native of America, and that it may be regarded, so to speak, as an original corn (*Zea mays*) parasite. It is now certainly widely distributed in maize-growing regions, but is more abundant under conditions of relatively high temperature. This fungus has also been reported on sorghum, but the maize fungus is distinct from *Puccinia purpurea*, now common in the southern United States and in the West Indies on certain species of sorghum. The uredospores are large, $23\text{–}30 \times 22\text{–}26\,\mu$, and the teleutospores are smooth, $28\text{–}45 \times 12\text{–}17\,\mu$, with a rather long and thick pedicel.

On maize the rust affects particularly the leaves and leaf sheaths, but it may cause considerable damage to the development of the tassels. Nevertheless, it seldom amounts to an epidemic, and consequently has not received attention from the standpoint of control, or of varietal selection of the host.

The maize fungus has recently been connected with an Æcidium (*Æcidium Oxalidis* Thüm.) on Oxalis, so that its heterœcism is established. This æcidial stage has seldom been found, and there is reason to believe that the uredo stage may commonly serve to carry the fungus over winter.

XV. TIMOTHY RUST

Puccinia Phlei-pratensis Eriks. & Henn.

ERIKSSON, J., u. HENNING, E. Die Hauptresultate einer neuen Untersuchung über die Getreideroste. Zeitsch. f. Pflanzenkr. **4**: 140–142. 1894.
ERIKSSON, J. Ueber die Specialisirung des Parasitismus bei den Getreiderostpilzen. Ber. d. deut. Bot. Ges. **12**: 292–331 (cf. 309–316). 1894.
KLEBAHN, H. Die wirtswechselden Rostpilze, *l. c.*, pp. 235–236.

Timothy rust is common in Europe, occasionally damaging to a noticeable extent the cultivated timothy (*Phleum pratense*). It also occurs upon some other cultivated and native grasses. The fungus is unquestionably closely related to *Puccinia graminis*, if not a form of this species. It is reported ineffective in producing the cluster cup of the barberry. During the past few years the timothy rust has been found in a considerable portion of the eastern United States, although previously it had not been noticed, at least to any practical extent. It is not yet positive that the rust which occurs in America is the same as the European species. It is conceivable that the cultivated timothy has gradually become susceptible to another form of *Puccinia graminis*, but this remains to be determined by careful experimental work. The European rust has not been connected with an æcidial stage, and it has been shown that the uredospores are apparently capable of wintering over, and therefore the disease may be readily reproduced from season to season without an æcidial stage. If the appearance in America means a sudden introduction and rapid spread of the European rust, much damage may be expected from it. On the other hand, it may have been parasitic upon timothy for some time without having attracted attention. Experiments made by Eriksson in the open indicate that the rusts on timothy and meadow fescue are readily transferred from one of these hosts to the other, and with much less success to several other grasses employed in the experiments.

XVI. BROWN RUST OF WHEAT AND RYE

Puccinia rubigo-vera De C.

ERIKSSON, J. Ueber die Specialisirung des Parasitismus bei den Getreiderostpilzen. Ber. d. deut. bot. Ges. **12**: 292–331. 1894.
FREEMAN, E. M. Experiments on the Brown Rust of Bromes (Puccinia dispersa). Ann. Bot. **16**: 487–494. 1902.
WARD, H. M. On the Relations between Host and Parasite in the Bromes [etc.]. Ann. Bot. **16**: 233–315. 1902.

Occurrence and nomenclature. The brown rust of wheat and rye is second only to the black rust in economic importance. In consideration of the detailed account of the black rust of wheat and other cereals and grasses, it will only be necessary in discussing the brown rust to draw attention to the chief points of interest by way of comparison. *Puccinia rubigo-vera* occurs upon a variety of grasses besides wheats and rye, among these certain species of Bromus, Lolium, and Elymus. The æcidial stage was by De Bary determined to be a form on a borage, *Anchusa arvensis*, known to occur also on *Anchusa officinalis*. The nomenclature of this rust is complex, and at the outset it may be said that Eriksson and Henning distinguish under the above name two species, and they have abandoned the name *Puccinia rubigo-vera* De C. One of these species is denoted the yellow rust, and to it is applied an old name, *Puccinia glumarum* (Schm.). The other species, designated brown rust, is made a new species and called *Puccinia dispersa*. The last named is found by inoculation to be connected with the æcidium on the borage hosts, while *Puccinia glumarum* is without known æcidial stage.

At any rate, these forms have not been commonly distinguished in the literature, and *Puccinia rubigo-vera* has been reported almost as widespread throughout the region of cereal production as the black rust. In the United States it is often unusually abundant in the central West. Bolley and others have shown that this fungus is able to carry itself through the winter by means of more or less continuous production of the uredo stage and by the mycelium in the leaves of winter grain.

The æcidia occur upon leaf blades, petioles, stems, and calyx of the borage hosts, producing rather conspicuous, bright yellow, slightly swollen spots.

It was very largely in characters of the uredosori and uredospores that there was found a means of distinguishing two species, or forms, as above mentioned. In the form *Puccinia glumarum* the uredosori are described as lemon-yellow, the sori united into long linear areas, while in the other form the sori are irregularly distributed over the whole surface and are described as brown-ocher in appearance.

The teleutospores form sori which remain covered by the epidermis; the one form is said to occur more upon leaf sheaths and stems, and the other upon the under surfaces of the leaves. Groups of teleutospores are arranged in fan-shaped masses surrounded by closely united, bent paraphyses. The spores are broader at the apex, irregular in form, more or less angular, generally 30–50 μ in length, and the upper cell 14–24 μ broad.

Both of the forms here mentioned are again divisible into several physiological races, each restricted to one or to relatively few hosts.

XVII. RUST OF STONE FRUITS

Puccinia Pruni-spinosæ Pers.

HOLWAY, E. W. D. North Amer. Uredinales **1**: 55–56. *figs. 83 a, 83 b.*
McALPINE, D. Peach- and Plum-Leaf Rust. Victoria Dept. Agl. Guides to Growers **5**: 1–8. 1891.
SCRIBNER, F. L. Leaf Rust of the Cherry, etc. U. S. Dept. Agl. Rept. (1887): 353–355. *pl. 3.*

This rust occurs throughout a considerable portion of southern North America. It is also found in Europe and Asia. It was introduced into Australia, apparently, somewhat earlier than 1883, and is now considerably distributed on that continent.

This fungus has been found on various species of the genus Prunus in the central and southern United States. It is reported upon such hosts as the peach (*Prunus Persica*); some of the native species of plum, such as *Prunus americana* and *Prunus domestica;* and on certain cherries, especially *Prunus serotina.* In other sections of the world it has also been noted on the almond (*Prunus Amygdalus*), on the apricot (*Prunus armeniaca*), and many other economic species. As a rule, this fungus is found upon the leaves, but it occurs also upon fruits of peach, almond, and apricot, and upon the stems of the peach under certain climatic conditions. No

striking discoloration of the leaves is produced at first, but the great number of sori which may be formed eventually give a light brown color to the leaf before it falls. Considerable defoliation may result, and it is stated that a shot-hole effect is sometimes produced upon the almond. The fungus is much more destructive in relatively moist, warm climates. It appears generally toward midsummer, but the most severe effects are commonly in the fall.

It has recently been determined that the æcidial stage of this fungus is *Æcidium punctatum*. Tranzschel was able to produce the rust by inoculations from the æcidium above mentioned on *Anemone coronaria*. These results were confirmed by Arthur with the æcidium from *Hepatica acutiloba*. This æcidium has a perennial mycelium in some of its hosts, so that this stage alone is believed to perpetuate itself.

The uredospores occur upon all hosts of the genus Prunus mentioned. They are generally hypophyllous, minute, cinnamon-brown, and may be so numerous as practically to cover the entire leaf. The spores are light brown, generally ovate or elliptical, with thickened apex. They are thickly verrucose and are provided with from two to three equatorial germ pores. They measure $20-36 \times 14-20\,\mu$. Paraphyses are abundant. Tranzschel determined that uredospores kept over winter at St. Petersburg were capable of germination the following spring.

The teleutospores generally appear in small groups among the uredospores and later supplant these entirely. The pustules are generally pulverulent and chestnut-brown. The teleutospores are from very light to reddish brown upon the different hosts. In general form they are elliptical, deeply constricted, and the two cells are more or less equal, often subspherical. They separate readily. These spores are provided with pointed tubercles. The spores measure $32-44 \times 20-26\,\mu$. The pedicels are slender, hyaline, and fragile. The lower portions of these become agglutinated into short columnar masses. The free portion of each pedicel is usually about the length of the spore.

XVIII. HOLLYHOCK RUST

Puccinia malvacearum Mont.

DUDLEY, W. R. The Hollyhock Rust. Cornell Agl. Exp. Sta. Bullt. **25**: 154–155. 1890.

FIG. 204. *PUCCINIA MALVACEARUM*: RUST OF HOLLYHOCK. (Photograph by H. H. Whetzel)

The hollyhock rust is known to infest a large number of genera and species of the mallow family (Malvaceæ). It is at present widely distributed throughout a large portion of the world, and is in the United States most important on the cultivated hollyhock (*Althæa*

rosea). The fungus is apparently a native of Chile and was not found in central Europe until between 1873 and 1877. It was evidently introduced into the United States prior to 1886 and has received special attention since about 1890.

On the hollyhock the fungus commonly occurs in such quantity that the proper development and normal functions of the leaves may be seriously inhibited. The sori are most abundant on the under surfaces of the leaves (Fig. 204), but they also occur upon other parts. They are at first small and circular in outline, but may become confluent over considerable areas.

During favorable conditions the teleutospores germinate immediately, and there is no evidence that the mycelium is generally perennial. Nevertheless, Fischer believes that in temperate climates the wintering over is ordinarily effected by means of teleutospores which fail to germinate on account of being overtaken by unfavorable conditions. The spores are light colored and measure $17–24 \times 35–63\,\mu$. They are often spindle-shaped, and the pedicel is long, frequently from 100 to $130\,\mu$.

This disease has been fairly well controlled by the destruction of diseased portions of plants and by spraying with Bordeaux mixture.

XIX. PUCCINIA: OTHER SPECIES

Puccinia Helianthi Schw. This euautouredo occurs commonly upon numerous species of Helianthus, including the sunflower (*Helianthus annuus*). Recent experiments indicate that the form on *Helianthus tuberosus* is at least physiologically distinct, and doubtless the species may be broken up into many forms. *Puccinia Helianthi* (with all spore stages) is distinguished from *Puccinia Tanaceti*, a related but apparently imperfectly known species, by the smooth apex of the teleutospore and the presence of only two germ pores in the uredospores.

Puccinia coronata Cda. This species has an æcidial stage upon the buckthorn (Rhamnus). At maturity the groups of cluster cups are very conspicuous by the color and also by the deformities. The æcidiospores measure $18–25 \times 14–19\,\mu$. The uredo and teleuto stages are common upon oats, and on such cultivated grasses as *Dactylis glomerata* and *Festuca sylvatica*. The uredosori are

bright yellow, the spores ovate, with roughened surfaces, measuring $28–32 \times 20–24 \mu$. The teleutosori remain covered by the epidermis, and the spores are notably distinctive in being cuneate in form, with several horn-like projections on the thickened apex, and with a very short pedicel. This species has also been broken up into diverse forms, some of which are considered distinct species.

Puccinia Chrysanthemi Roze. The chrysanthemum rust[1] has been of some consequence in Europe and America during the past fifteen years. It was common in Japan at a much earlier time. The principal hosts are *Chrysanthemum indicum* and *Chrysanthemum sinensc*. In the warmer coastal regions of Japan and in Europe and America continuous generations of uredospores may be produced. In these places teleutospores occur rarely. When they occur, mesospores and irregularly formed uredospores are also common. In the cooler portions of Japan teleutospores are commonly found in the autumn. It would appear that uredospores and teleutospores are the only stages in the normal life cycle of this species. In greenhouse culture this rust is generally controlled by resistant stock and care in watering.

Puccinia Tragopogi (Pers.) Cda. This species, occurring on members of the genus Tragopogon, and especially on the cultivated form, *Tragopogon porrifolius*, is not uncommon in gardens where salsify is annually grown. It is constantly without uredospores and exhibits the anomalous condition of producing also unicellular teleutospores. There is, moreover, great variability in the size of this spore form.

Puccinia suaveolens (Pers.) Rostr. The characteristic odor, or aroma, of the spermogonia is a distinctive peculiarity of this species. It is considered to be a means of attracting insects, perhaps for purposes of distribution. It will be recalled, however, that the spermatia are not known to be at present effective in the propagation

[1] Arthur, J. C. Chrysanthemun Rust. Ind. Agl. Exp. Sta. Bullt. **85**: 143–150. 1900.

Jacky, E. Der Chrysanthemum-Rost. Zeitsch. f. Pflanzenkr. **10**: 132–142. 1900.

Kusano, S. Biology of the Chrysanthemum-Rust. Bullt. Coll. Agl. Imp. Univ. Tokyo **8**: (reprint 1–10). 1908.

Roze, E. Le Puccinia Chrysanthemi, etc. Bull. de la Soc. Myc. de France **16**: 88–93. 1900.

of any rust. The spermogonia are extremely numerous, covering practically both surfaces of the leaf, while the uredo and teleutosporic sori occur on the under surface of the leaves only. In the first generation the sori are confluent, but in the second generation distinct. This species occurs on the common Canada thistle (*Cirsium arvense*). Infection from the teleutospores produces a mycelium which deforms the host, but the infection from uredospores produces a localized mycelium. These differences upon the same host suggest a condition which may be regarded as biologically intermediate between true autœcism and heterœcism.

Puccinia Hieracii (Schum.) Mart. This rust occurs on various species of Hieracium, and from the observations made it would also appear to be a species embracing many different forms.

Puccinia fusca Relhan. This rather variable species is parasitic upon certain anemones, and the mycelium has been experimentally determined to be perennial in the host.

XX. GYMNOSPORANGIUM

FARLOW, W. G. Notes on Some Species of Gymnosporangium and Chrysomyxa in the United States. Proc. Amer. Acad. Arts and Sci. **20**: 311–323. 1885.

FARLOW, W. G. The Development of the Gymnosporangia of the United States. Bot. Gaz. **11**: 234–241. 1886.

FARLOW, W. G. The Gymnosporangia (Cedar-Apples) of the United States. Anniv. Mem. Boston Soc. Nat. Hist. 38 pp. *2 pls.* 1880.

PAMMEL, L. H. The Cedar Apple Fungi and Apple Rust in Iowa. Iowa Agl. Exp. Sta. Bullt. **84**: 1–36. 1905.

RICHARDS, H. M. The Uredo-stage of Gymnosporangium. Bot. Gaz. **14**: 211–216. *pl. 17.* 1889.

THAXTER, R. Notes on Cultures of Gymnosporangium made in 1887 and 1888. Bot. Gaz. **14**: 163–172. 1889.

THAXTER, R. The Conn. Species of Gymnosporangium (Cedar-Apples). Conn. Agl. Exp. Sta. Bullt. **107**: 1–6. 1891.

There is, perhaps, no genus of rust fungi comprising several or more species which is as uniform in developmental processes as the genus Gymnosporangium. Aside from a direct agreement in the sequence of spore forms, and in the general relations of these forms one to another in the different species, all have the same spore forms, namely, spermogonia, æcidia, and teleutospores; and in the different species the same spore forms appear in almost the identical season.

There are about fifteen species of these fungi, all but one of which have the æcidial or rust stage (Rœstelia) on some member of the tribe Pomeæ, generally apple, pear, or crab (Pyrus), quince (Cydonia), shad bush or service berry (Amelanchier), or hawthorn (Cratægus). The teleutosporic stage, which is commonly produced on hypertrophied parts in the nature of "cedar apples," witches' brooms, and other deformities of the host, generally occurs upon one of the species of red cedar or juniper (Juniperus); only two species of these fungi are exceptions, these having as a host the related genus Cupressus. These fungi are of economic interest

FIG. 205. ÆCIDIAL STAGE OF GYMNOSPORANGIUM ON FRUIT OF HAW

because of the injuries to fruits and leaves of the Pomeæ, and not as a rule because of serious injuries to the coniferous hosts.

On account of the great similarity in development, the general facts of life history import may be collectively presented. Moreover, since in the order of season the teleutosporic form occurs first, the discussion will follow this plan.

Soon after the growing season begins, and following a warm rain, there will be found protruded from the cedar apples, or from enlargements on the twigs of other conifers mentioned, gelatinous, orange-colored spore masses, sometimes horn-like, and again almost shapeless. These masses consist, in large part, of orange-tinted

teleutospores with long, gelatinizing pedicels (Fig. 206). These teleutospores germinate immediately. Three promycelia often arise from a spore, each through a germ pore situated near the septum between the two cells. The promycelium may form four sporidia in the usual manner, and these sporidia cannot reinfect the cedar. They may apparently be borne long distances by the wind. Moreover, they are produced during the season when young leaves and fruits are abundant on the apple, quince, and such plants. Falling upon the congenial host, the spore immediately germinates, and infection is secured. In time the rust stage of the fungus appears. This stage consists of spermogonia and æcidia. It is then perhaps midsummer, and the abundant æcidiospores return the fungus to the conifer host, where in time a gall or a deformity is again produced.

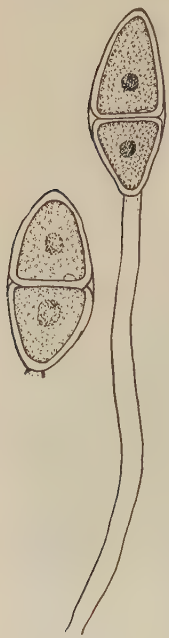


FIG. 206. *Gymnosporangium macropus*: Teleutospores

The rust spots on the pomaceous hosts appear at first as clear yellow or orange areas, slightly thickened or raised. Soon a papillate appearance indicates the presence of the spermogonia or pycnidia, which are all of a characteristic, simple type. The æcidia follow in a brief period on the under side of the leaf, or covering large areas on the fruit (Fig. 205). The æcidium (rœstelia) is an organ of some length, appearing cylindrical or jug-shaped after emergence. A circular orifice is developed, and the peridium breaks into a characteristic margin, sometimes fimbriate. The spores, which are produced in chains, break apart when mature. They also germinate immediately.

Control consists primarily in the removal of the cedars, if that is practicable. Attention should also be paid to the resistance of varieties of apples grown. It is, moreover, of some value to spray with the standard Bordeaux mixture at about the time of ripening of the teleutospores.

XXI. CEDAR APPLES AND APPLE RUST

Gymnosporangium macropus Lk.

This is one of the most widespread and economically important of this genus. It produces the large cedar apples on *Juniperus virginiana* (Fig. 207). This fungus occurs practically throughout

FIG. 207. *GYMNOSPORANGIUM MACROPUS:* CEDAR APPLE

the range of the red cedar and its other hosts. The æcidial stage occurs on the apple (*Pyrus Malus*) and also on *Pyrus coronaria*, and was originally described as *Rœstelia Pyrata* (Schw.) Thaxter. On the leaves some injury is done to these plants when the

infection is severe, but it is upon the fruit that the fungus becomes, in many sections of the United States, a serious disease. It is far more common in regions of considerable humidity, but owing to the fact that teleutospores are produced during wet weather, infection is usually immediately assured upon the pomaceous hosts in the vicinity. The fungus has been noticeably abundant in apple-growing regions in the eastern Appalachians and in the South. Varieties of apples differ greatly in their susceptibility. In the far West, crosses between the wild crab apple and the cultivated species have given some forms peculiarly susceptible. The gall formation on the cedar commonly attains a diameter greater than 2 cm., and when the horn-like gelatinous sori are developed, the mass from edge to edge may measure 8 cm. The teleutospores are $46–60 \times 15–20 \mu$.

XXII. GYMNOSPORANGIUM: OTHER SPECIES

Gymnosporangium clavariæforme (Jacq.) Rees is a species unusually abundant in the northeastern United States. The teleutosporic form occurs on the common or dwarf juniper (*Juniperus communis*). Slight enlargements of the twig are produced, and the sori are orange-red in appearance. In America the æcidia occur on the hawthorn (*Cratægus tomentosa*), while in Europe they are also produced upon *Cratægus oxyacantha*, *Cratægus monogyna*, *Pyrus communis*, and occasionally other pomaceous trees. This species is apparently not so fixed in its specialization with respect to hosts for the æcidial stage as other members of this genus.

Gymnosporangium globosum Farl. This species produces on the red cedar (*Juniperus virginiana*) smaller cedar apples than the preceding, and they are also distinguished from the latter by the texture of the gall, the deeper color of the spore masses, and certain spore characters.

This fungus is a chief cause of the apple rust of the New England States, and the rœstelia stage is also found on the pear, quince, and some varieties of mountain ash.

Gymnosporangium Sabinæ Plowr., which is closely related to *Gymnosporangium globosum*, has also the same coniferous host. The æcidial stage has for some time been recognized as injurious to pear culture in Europe.

XXIII. ORANGE RUST OF RASPBERRY AND BLACKBERRY

Gymnoconia Peckiana (Howe) Tranz.

CLINTON, G. P. Orange Rust of Raspberry and Blackberry. Ill. Agl. Exp. Sta. Bullt. **29**: 273–296. *pls. 1–4*. 1893.

FARLOW, W. G. Notes on Some Species in the Third and Eleventh Centuries of Ellis's North American Fungi. Proc. Amer. Acad. Arts and Sci., N. S. **18**: 65–85 (76). 1883.

NEWCOMBE, F. C. Perennial Mycelium of the Fungus of Blackberry Rust. Journ. Mycology **6**: 106–107. *pls. 5, 6*. 1890.

RICHARDS, H. M. On the Development of the Spermogonium of Cæoma nitens (Schw.). Proc. Amer. Acad. Arts and Sci., N. S. **20**: 30–36. *pl. 1*. 1893.

TRANZSCHEL, W. Culturversuche mit Cæoma interstitiale Schlechtd. (= C. nitens Schw.). Hedwigia **32**: 257–259. 1893.

Occurrence and symptoms. The orange rust is a common disease of black raspberries and blackberries throughout portions of the United States and Canada, and it is also widely distributed in Europe and Asia. It is found upon various species of the genus Rubus, whether wild or cultivated, although there is considerable difference in the susceptibility of different varieties of the same species. Among raspberries Clinton has cited the Kittatinny as perhaps the worst affected, and the Snyder as notably resistant. In other regions, however, the latter has proved less resistant. The fungus may be noted almost as soon as the young leaves begin to appear in the spring. The spermogonial stage appears first and gives to the surface of leaves and even young stems a glandular appearance, which may often be mistaken for a natural condition. A comparison, however, of affected with unaffected plants readily demonstrates the specific effects of the fungus. At times the spermogonia are, however, limited in distribution, affecting only a portion of the leaves of a bud, or merely small areas upon a single leaf. In from ten to fifteen days after the appearance of the spermogonia the striking æcidial stage may be found appearing only on the lower surface of the leaf. The cushions which produce the spores are rapidly developed beneath the epidermis, and upon the rupture of the latter the bright orange spores are disclosed. Eventually the under surfaces of the leaves may appear to be covered with a continuous mass of more or less adhesive orange-red material. All of the vegetative parts of the plant which are affected are usually greatly impaired in vitality and

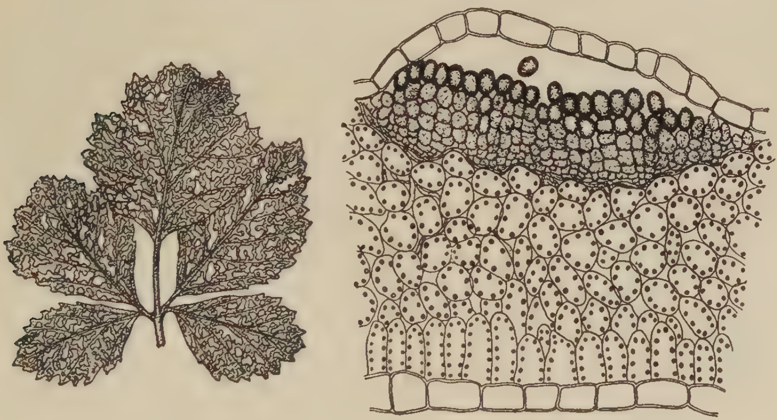
frequently appear spindling from the beginning. Nevertheless, the affected shoots or canes may not be killed, and the disease may reappear upon such affected plants the following year from the growth of the mycelium into young shoots. In the end, practically all affected plants are killed, and their vitality is from the outset so diminished that productiveness is impossible.

FIG. 208. BLACKBERRY RUST, CÆOMA STAGE
To the left, normal shoots; to the right, diseased

The fungus. The mycelium of this fungus has been carefully studied in the growing canes. It is intercellular, and grows rapidly in the direction of formative tissues, or where new cells are being produced, extending but slightly into tissues or organs which have matured. The mycelium is richly provided with haustoria. The tip of the haustorium enlarges as a knob-like organ, and this is commonly more or less in contact with the cell nucleus. The mycelium in the root penetrates the parenchymatic cortical cells,

and in the regions where the hyphæ are abundant the amount of starch is distinctly less than in those not pervaded by the fungus. In the stem, according to Clinton, the mycelium is found especially in the pith, in a more or less zonal area situated near the fibrovascular system. The young mycelium is more readily seen on account of the greater amount of coloring matter which it contains.

The structure of the spermogonial stage has been carefully studied by Richards. His work indicates that the spermogonia arise as a bundle of septate threads which press against the surrounding



a *b*

FIG. 209. CÆOMA STAGE OF *GYMNOCONIA PECKIANA*. (After Clinton)

a, general effect on leaf; *b*, cross section through a young sorus

cells so as to cause them to collapse, and these injured cells are finally penetrated by the mycelium. On reaching full growth small spore-like bodies are abscised from the ends of each thread; and when produced in quantity, the epidermis is ruptured, or punctured, and the spores ooze out as a small glandular droplet. It has not been shown with certainty that these spores have been germinated. The observations upon a budding habit suggested by early observers may have concerned themselves with yeast cells associated with the spores and accidentally introduced into the culture drop.

The æcidial or cæomal stage may cover practically the whole of the lower surfaces of the leaves. This stage is the one of great importance from the standpoint of the propagation or dissemination of this fungus. In the formation of the spores extensive mycelial cushions are developed near the lower surface of the leaf, and from these cushions there arise cells perpendicular to the surface, which elongate, and in time originate chains of the æcidiospores. The development of these spores effects a rupture of the epidermis, so that the mature spores are exposed (Fig. 209). The maturity of the spore involves the development of a considerable amount of coloring matter in the protoplasm, so that when the spores are exposed, the under surface of the leaf is bright orange. The spores are ordinarily ovoidal or more or less globose, sharply verrucose, and measure $12-24 \times 18-32 \mu$. Germination may take place immediately upon maturity of the spores, and the Rubus hosts may be promptly infected. The lack of a true peridium in this stage is the chief reason for separating the species generically from species of Puccinia.

The teleutosporic form of this species is of the Puccinia type. Prior to the experiments of Tranzschel and Clinton, working independently, it bore the name *Puccinia Peckiana*. The teleutosporic form is relatively far less abundant than the other stages. The chief peculiarity is found in the location of the germ pore in the basal cell, which is always considerably below the dividing wall.

XXIV. RUST OF ROSES

Phragmidium subcorticium (Schrank) Wint.

Bandi, W. Beiträge zur Biologie der Uredineen (Teil I). Hedwigia **42**: 118–136. 1903.

The various species of Phragmidium are parasitic upon different rosaceous hosts. No species of these rusts produces any very serious disease of a cultivated variety; nevertheless, consideration should be given to a general study of one member of this genus. The fungus above indicated occurs commonly in moist regions upon several wild roses. Spermogonia and æcidia (cæoma type) are produced on the stems, petioles, leaf veins, etc., as orange-red pustules, sometimes inclosed by paraphyses. The spores are

produced in short chains and measure $24–28 \times 18–21\,\mu$ (Fig. 210, *b*). The uredesori occur on the under surface of the leaf. They are somewhat lighter colored than the cæoma and are constantly inclosed by paraphyses. Individual spores are about the same in size and form, however, as the previous type (Fig. 210, *c*). In the same sori with the latter may be produced also the teleutospores,

FIG. 210. *PHRAGMIDIUM SUBCORTICIUM*
a and *d*, cæoma and teleuto stages on rose; *b*, *c*, and *e*, spore forms

usually in small black groups. A teleutospore is more or less spindle-shaped, usually six to eight cells in extent (Fig. 210, *e*), and each cell is provided with several germ pores. The outer wall of the spore is generally uneven or warty toward the apex, and there is a distinct terminal papilla. The teleutospores measure $65–100 \times 30–45\,\mu$ without the pedicel. The pedicel is persistent, swollen at the base, and about as long as the spore. The cells of the teleutospore adhere closely, while in some other species they separate readily on maturity.

XXV. RUST OF RHODODENDRON AND NORWAY SPRUCE

Chrysomyxa Rhododendri (De C.) De Bary

Occurrence. The rhododendron rust is especially abundant in portions of Europe and America, particularly in regions where the wild species of the rhododendron and of the fir grow together in the same forest areas. In fact, the rust is the most common fungus of the rhododendron, and in regions where the fir abounds the rhododendron is seldom free from its attacks. In Europe it is notably abundant on *Rhododendron hirsutum* and on *Rhododendron ferrugineum*, these being the hosts upon which the uredo and teleuto stages are found. The spermogonial and æcidial stages are confined to the fir (*Picea excelsa*). In the United States this fungus is particularly common in the mountains of the East, and southward as far as the southern limits of the Appalachians.

The spore forms. The spherical spermogonia appear upon young leaves of the fir in the spring, and these are followed a month or more later, sometimes as late as midsummer, by the æcidial stage. The æcidia break through the epidermis of the leaf as more or less tuberculate structures arising thickly on the under surfaces of the leaves to a height of two or three millimeters, each producing numerous æcidiospores. The latter germinate readily, and the host is penetrated by means of the stomata. It is claimed that the mature leaves of the rhododendron are those generally infected. The mycelium developed in such persistent, or evergreen, leaves winters over and produces abundantly the uredo stage, followed also by the teleutosporic stage. The uredo stage serves to spread rapidly the fungus from one plant to another during the growing season. The teleutosporic stage, however, germinates immediately, and the basidiospores penetrate the young shoots of the fir, thus completing the life cycle of this euheterouredo. The uredosporic pustules appear only on the under surfaces of the leaves, or occasionally on the younger stems, and these spores are borne in chains with alternate sterile cells. The teleutospores are closely adherent in groups. They are more or less cylindrical in form, extremely light in color, and vary as to the number of cells from three to six, those at the center of the group showing the larger number of cells.

Control. No attempts have been made to control this disease, and it is doubtful if any effective method could be found, except that of excluding one or the other of the two hosts from any particular region. It is, moreover, possible that the uredo stage may serve to transmit the disease from season to season upon the rhododendron.

XXVI. THE EUROPEAN CURRANT RUST

Cronartium Ribicola Fisch. de Waldh.

HENNINGS, P. Beobachtungen über das verschiedene Auftreten von Cronartium ribicola Dietr. auf verschiedenen Ribes-Arten. Zeitschr. f. Pflanzenkr. **12**: 129–132.

KLEBAHN, H. Ueber die Formen und den Wirthswechsel der Blasenroste der Kiefern. Ber. d. deut. bot. Ges. **8**: (59)–(70). 1890.

KLEBAHN, H. Neue Untersuchungen und Beobachtungen über die Blasenroste der Kiefern. Hedwigia **29**: 27–35. 1890.

PLOWRIGHT, C. B. Fungus on Weymouth Pine and on Currants. Gard. Chron. **12** (III): 44. 1892.

STEWART, F. C. An Outbreak of the European Currant Rust. N. Y. Agl. Exp. Sta. Tech. Bullt. **2**: 62–74. *pls. 1–3.* 1906.

v. TUBEUF, K. Infektionsversuche mit Peridermium Strobi, dem Blasenroste der Weymouthskiefer. Arbeiten aus der Biolog. Abt. f. Land- u. Forstwirtschaft am Kaiserl. Gesundheitsamte **2**: 173–175. 1901. (Abstract in Centrbl. Bakt. u. Parasit. **7** (Abt. II): 445.)

Occurrence. Until within the past few years this fungus was known to be of importance only in Europe, and indeed as yet only sporadic cases have been found in other parts of the world. At Geneva, N. Y., there was an outbreak on currants during 1906, and special measures were taken to stamp out the fungus in that vicinity. It appears also that the fungus is known in India. The æcidial stage of this fungus was named *Peridermium Strobi*, by Klebahn, but inoculation experiments made subsequently both by the author of this species and by others have demonstrated its connection with the uredo and teleuto forms found on currants. The æcidial stage has been reported most destructive to the white pine (*Pinus strobus*) in many parts of Europe. The injuries caused by the uredo and teleuto stages upon the currant are, however, not of sufficient importance, of themselves, to arouse particular interest. In this connection it is instructive to note that the white pine is a native of America; and it seems remarkable, when the susceptibility of this species in Europe is considered, that the

fungus should not long ago have appeared in America.[1] The æcidial stage is also found upon another species of pine, *Pinus cembra*, and it is believed by some that the fungus is indigenous upon this species in Russia and in Switzerland.

Host plants. The uredo and teleuto stages (Fig. 211) occur upon many varieties of the genus Ribes, representing several

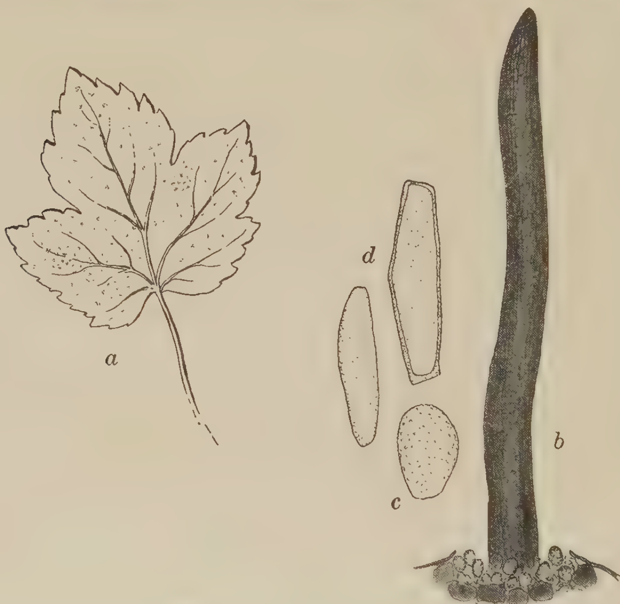


FIG. 211. *CRONARTIUM RIBICOLA*

a, sori on currant leaf; *b*, sorus and teleutosporic column; *c* and *d*, uredospores and teleutospores

[1] During June, 1909, the æcidial stage of this fungus was found in a nursery of three-year-old white pine seedlings imported from Germany. Many seedlings of this importation have been distributed to several northeastern states and to Canada. A determined effort is being made to inspect all plantings, to destroy the diseased stock, and also to prevent further importation of the infected white pine seedlings. Inspection of such seedlings at the time of importation is practically valueless, since the fungus has an incubation period in the bark of nearly one year before the characteristic swellings appear. Details of the outbreak in New York are discussed in the following articles:

Atwood, G. G. Blister Rust of Pines and the European Currant Rust. Dept. Agl., State of N. Y. Hort. Bullt. **2**: 1–15. 1909.

Spaulding, Perley. European Currant Rust on the White Pine in America. Bur. Plant Ind., U. S. Dept. Agl. Circular **38**: 1–4. 1909.

different species. According to Stewart forty-eight out of fifty-four varieties of currants were affected in one plantation in the Geneva outbreak, representing the three species *Ribes nigrum*, *Ribes rubrum*, and *Ribes aureum*. The only varieties which were free from the fungus in this attack were the following: Prince Albert, Gondouin White, Stultz, and an unknown variety, all of *Ribes rubrum*, and Crandall and Utah Golden of *Ribes aureum*. In another plantation where sixteen different species of Ribes were cultivated, only one species, *Ribes irriguum*, was rusted, but these plantations did not include *Ribes nigrum* and *Ribes rubrum*.

Control. In attempting to control or stamp out this disease, it would seem, with the information at hand, that the only hope would lie in the destruction of one or the other of the two hosts, the currant or pine. It is assumed in this connection that the two host plants are invariably essential to the maintenance of the fungus. Since the fungus appears to be of little importance as a disease of currants, the growers of this fruit evidently will not resort to heroic measures, and it will devolve upon foresters to watch closely for the fungus, and if it appears, eliminate the wild species of Ribes from the forest area.

XXVII. ORANGE RUST OF ASTER AND GOLDEN-ROD

Coleosporium Solidaginis (Schw.) Thüm.

ARTHUR, J. C., and KERN, F. D. North American Species of Peridermium. Bullt. Torrey Bot. Club **33**: 403–438. 1906.

CLINTON, G. P. *Peridermium acicolum*, the Æcial Stage of Coleosporium Solidaginis. Science **25**: 289–290. 1907.

CLINTON, G. P. Heterœcious Rusts of Connecticut having a Peridermium for their Æcial Stage. Conn. Agl. Exp. Sta. Rept. (1907): 369–396. *pls. 25–32.*

Occurrence. Of the several species of Coleosporium having uredospores and teleutospores on species of Compositæ, there is none of such common occurrence throughout North America as the species here discussed. To this species are referred the orange rusts of many species of Aster and Solidago (golden-rod). It includes also as hosts representatives of several other genera, among which is the cultivated aster (*Callistephus hortensis*). This fungus is by many regarded as identical with a species occurring widespread in Europe upon Senecio.

The genus Coleosporium is to be considered entirely heterœcious, and whenever æcidial stages are known in the life cycle, they occur on species of Pinus, and are referable to the form genus Peridermium.

The æcidial stage of the species here discussed has recently been found through inoculation experiments to be a form known as *Peridermium acicolum* occurring on leaves of *Pinus rigida* in several of the northeastern states. The European form occurs upon branches and stems of *Pinus sylvestris*.

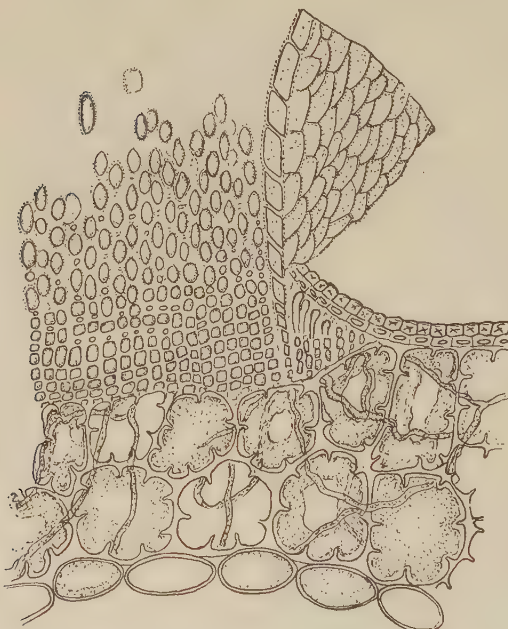


Fig. 212. Peridermium on Pine. (After Hartig)

The fungus. The uredo and teleuto stages are merely conspicuous by their color, and in this particular instance the æcidial stage is by no means striking. Other forms or species of Peridermium, however, may produce considerable swellings upon their hosts.

According to Clinton the infection of young pine leaves may take place in spring, the æcidia resulting the following year. It would appear that the Peridermium is inessential for the continuous propagation of the rust upon composites in the United States, since the uredo stage is produced practically throughout the winter on leaves of the basal rosettes.

The spermogonia appear upon the needles in autumn, but the æcidia are not developed until spring. They occur on both surfaces of the leaves in slightly discolored spots. They are crumpent,

tongue-shaped bodies .5–.7 mm. high, opening by an irregular rupture of the peridium. The spores are, according to Arthur, coarsely verrucose with deciduous tubercles, except along one narrow line, where tubercles fail.

Fig. 213. *Coleosporium Senecionis* (*b* after Tulasne)

The uredospores are produced in orange-yellow sori, which soon fade to nearly white. They are generally ellipsoidal, measuring $27–30 \times 17–22\,\mu$. The teleutospores are borne in crowded waxy masses, and are at maturity a chain of four basidial cells within a somewhat gelatinized common wall. They are sessile, $55–80 \times 15–23\,\mu$, and the cell wall at the apex is generally swollen, often attaining a maximum thickness of $30–40\,\mu$.

XXVIII. RUST OF POPLAR

Melampsora tremulæ Tul.

Tulasne applied the above name to a rust of the poplar (*Populus tremula*) occurring throughout a considerable range in Europe. It would seem that this name would now include at least three forms, or species, as distinguished by Klebahn, viz., *Melampsora Pinitorqua* Rostr., *Melampsora Larici-tremulæ* Kleb., and *Melampsora Magnusiana* Wagn. These

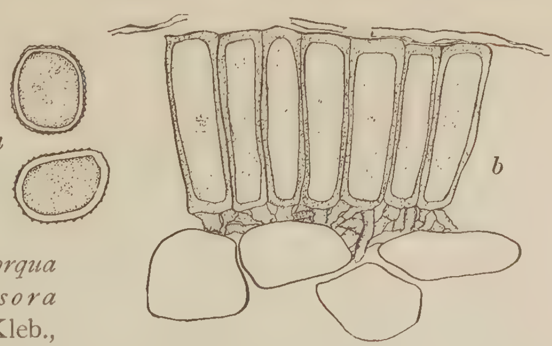


Fig. 214. *Melampsora tremulæ:* Uredospores and Teleutospores

three forms, together with one discussed by Klebahn as *Melampsora Rostrupii* Wagn., all agree in having more or less spherical uredospores, and in no case are there marked morphological differences in the uredospores or teleutospores within this group. The cæoma stages have, however, been determined, for these forms, to occur respectively upon Pinus, Larix, Chelidonium and Corydalis, and Mercurialis. For our purpose, it does not matter particularly whether these forms are considered a group of closely related species, or merely well-established physiological forms of a single variable species. In Europe these are found chiefly upon *Populus tremula* and *Populus alba*. In the United States it would seem difficult at the present time to name the hosts positively, although *Populus tremuloides* may be specially mentioned.

CHAPTER XV

AUTOBASIDIOMYCETES

In this class the sporophore or mycelial body may be of most diverse form. The most essential character, however, is that ordinarily a portion of the sporophore is eventually differentiated into a close layer, the hymenium, from which arise, in a palisade manner, clavate or cylindrical basidia. Each basidium produces four (occasionally two, six, or eight) unicellular basidiospores, each on a relatively short sterigmatum. The fruit body, or sporophore, may reach, in this class, the maximum size and complexity attained among fungi.

I. EXOBASIDIALES (EXOBASIDIACEÆ)

Brefeld, O. Die Gattung Exobasidium. Unters. a. d. Gesamtgeb. d. Myk., **8**: 12–18. 1889.

Geyler, H. Th. Exobasidium Lauri, nov. sp. Bot. Zeit. **32**: 321–326. *pl. 6.* 1874.

Woronin, M. Ueber die Sclerotienkrankheit der Vaccinienbeeren. Mém. acad. imp. de St.-Pétersbourg **36** (Sér. 7): 28–30. 1888.

The members of this order are distinguished from other Basidiomycetes chiefly in two characteristics, first, that the mycelium is strictly parasitic, producing generally a gall-like hypertrophy made up of mycelium and host tissue ; and second, that there is produced no definite sporophore; instead, the basidia break through the epidermis of the host.

Four sporidia are commonly produced (occasionally five or six). The spores are curved, and germinate in nutrient media, so far as known, after one or more cross partitions are formed. Germination is then more or less equivalent to a budding process, in which numerous spindle-shaped cells are produced.

The genus Exobasidium is most important, and the majority of the species produce deformities upon different genera of heaths (Ericaceæ).

II. GALL OF HEATHS

Exobasidium Vaccinii (Fckl.) Wor.

RICHARDS, H. M. Notes on Cultures of Exobasidium Andromedæ and of Exobasidium Vaccinii. Botan. Gaz. **21**: 101–108. *pl. 6.* 1896.
SHEAR, C. L. Cranberry Diseases. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **110**: 35–37. *pl. 7.* 1907.

Relationship of forms. Much cross-inoculation work is needed to determine the relationship between forms of Exobasidium on different species of heath (Ericaceæ). These fungi are found upon certain more or less closely related hosts, generally in bog-like habitats throughout considerable portions of Europe and North America.

FIG. 215. *EXOBASIDIUM VACCINII* ON RHODODENDRON

The fungus upon *Vaccinium Vitis-idæa* is considered the typical form of the species here discussed. Upon the host referred to, pale rose or reddish, thickened spots are produced. The same species occurs, apparently, on other species of Vaccinium, also Gaylussacia and other genera, and it may be well briefly to refer to some of its related forms. No morphological characters of the fungus above mentioned have been found which would distinguish it from *Exobasidium Oxycocci* Rostr. on the cranberry (*Vaccinium macrocarpon*). On the cranberry, however, lateral buds are attacked, and as these exfoliate, a considerable portion of the shoot may become hypertrophied. The affected leaves are rose colored, and since they remain close together on the shoot, they are often called false blossoms. A form producing characteristic galls on the young shoots of several species of rhododendron is generally regarded as distinct, and bears the name *Exobasidium Azaleæ*. Finally, there is an unusually large form described as *Exobasidium Andromedæ* Pk., which produces

distortions on young shoots of *Andromeda ligustrina*. Galls of this latter form are hollow, bag-like structures which may attain a length of five or six inches.

Richards employed the large form on Andromeda and *Exobasidium Vaccinii* in some cross inoculations and was able to develop the leaf spot form of the gall on Andromeda from *Exobasidium Vaccinii*, and also to produce this same form through spores from the galls on Andromeda. He also directs attention to the fact that the larger distortions in general are produced only during the early part of the year, that is, when the fungus attacks the young and sensitive tissue. Cross-inoculation work is attended with some difficulty on account of the diversity in season of the various forms, and probably also differences in the susceptibility of the hosts as the season advances.

FIG. 216. *EXOBASIDIUM VACCINII* (After Woronin)

The fungus. The hyphæ are fine, much branched, and commonly intercellular. They are most abundant in the subepidermal layers, and in the case of the forms producing galls upon the young stems they are more or less confined to the cortical parenchyma. The basidia arise directly from the hyphæ, pushing up between the epidermal cells. A basidium bears frequently four spores, but two to seven may be produced. The spores are elliptical or slightly curved and ordinarily measure $14-17 \times 3\,\mu$. Among the basidia, at intervals, may appear certain branched conidiophores bearing small acicular conidia. This is apparently the chief conidial type in the genus Exobasidium.

III. HYMENOMYCETALES

Among the higher Basidiomycetes the important forms from the view point of the economic plant pathologist are included in a few families of the Hymenomycetales. This order includes the

great majority of the plants commonly known as mushrooms, toad-stools, punks, etc., plants exceedingly variable in size, form, and texture. The mycelium is generally abundant, and it is made up of relatively minute hyphæ in loose wefts or flocculent masses, sometimes closely united into bands or strands (rhizomorphs), and often perennial. Sclerotia also occur. The fruit body varies from what is merely a close hyphal weft to bodies most diversely constituted, and very complex in structure (sporophores). In fact, the fruit body may be felt-like, pellicular, leathery, fleshy, corky, or woody in texture. Conidial stages of several types are present in some families, but in this group these imperfect forms have not the same relative significance in propagation as in the Ascomycetes. The mycelium of a majority of the parasitic or wood-destroying species may be grown in artificial cultures in the laboratory. Frequently the best growth is obtained when such materials as dead wood, decayed leaves, and rich soil are substituted for the usual media.

The families and genera here to be considered consist of solid sporophores, briefly characterized as follows:

1. *Thelephoraceæ*. The hymenial surface is more or less smooth. Sporophores are skin-like, gelatinous, or woody in texture, spread out over the surface of the substratum (resupinate), shelving, stalked, or considerably branched. Corticium and Stereum are important genera.

2. *Hydnaceæ*. The hymenial surface is usually spread over tooth-like divisions of the sporophore, the latter, however, sometimes wart-like or even more or less briefly plate-like (lamelliform). The sporophores are very diversely formed. The genus Hydnum alone will be considered.

3. *Polyporaceæ*. The hymenial surface is generally spread over the inner surfaces of pores or narrow tubes, sometimes, however, over folds or shallow depressions between vein-like reticulations, occasionally more or less lamelloid. The sporophores are diverse, generally tough, often very large. Those most important in the production of tree diseases are typical pore-bearing species, which may be assigned to one of three closely related genera, — Fomes, Polyporus, and Trametes.

4. *Agaricaceæ*. The hymenial surface is confined to radial plates or lamellæ, the latter, however, sometimes in the form of

folds or veins. The sporophores are generally fleshy, with a definite cap, or pileus, usually provided with a central stalk, but also excentric, sessile, etc. Marasmius, Clitocybe, and Armillaria are some of the principal parasitic genera.

Corticium, including resupinate species without setæ (cystidia) on the hymenium. The spores are generally small, hyaline, and without appendages.

Stereum is a diverse genus with broader characteristics. The sporophores are differentiated into several layers. They are only partially if at all resupinate, and often shelving, or even slightly stalked.

Hydnum. The sporophores are provided with awl-like teeth arising from tuberculate, branched, or cap-like portions of the sporophore. No cystidia are present.

Fomes, with sporophores generally bracket-like or hoof-shaped, sessile or stalked, and woody even when young. The pores are narrow, and the tissue between these is heterogeneous with the general tissue of the sporophore.

Polyporus is similar to the preceding, except that the sporophore is at first fleshy, becoming harder, and it may be exceedingly diverse in form and size.

Trametes. In this genus the species are generally of the texture of Fomes or Polyporus; but the general tissue of the sporophore penetrates between the pores, so that there is homogeneity of substance.

Marasmius is a genus of the relatively small gill-bearing fungi in which the plants become dry, yet, when remoistened, regain much their original forms. The cap is fleshy to leathery, the gills tough and distant, producing white spores, and the stipe cartilaginous or horny.

Clitocybe, with more or less fleshy cap and stalk, the latter centrally placed, is characterized by decurrent gills (lamellæ) and by the absence of any appendages, such as veil or volva. The spore powder is white and the spores hyaline.

Armillaria. These forms are quite similar to the preceding except that when young the cap is attached to the stem by a veil, which upon breaking forms a more or less persistent ring (annulus) on the stem.

IV. A ROOT AND STEM ROT FUNGUS

Corticium vagum B. & C., var. *Solani* Burt.

Atkinson, Geo. F. Some Diseases of Cotton. Ala. Agl. Exp. Sta. Bullt. **41**: 30–39. 1892.
Clinton, G. P. Rhizoctonia (Rosette). Conn. Agl. Exp. Sta. Rept. (1904): 325–326. *pl. 26. figs. a–c.*
Duggar, B. M., and Stewart, F. C. The Sterile Fungus Rhizoctonia. Cornell University Agl. Exp. Sta. Bullt. **186**: 50–76. *figs. 15–23.* 1901. Ibid. N. Y. (Geneva) Agl. Exp. Sta. Bullt. **186**: 4–30. *figs. 15–23.* 1901.
Pammel, L. H. Preliminary Notes on a Root-Rot Disease of Sugar Beets. Iowa Agl. Exp. Sta. Bullt. **15**: 243–251. *pls. 3–4.* 1891.
Rolfs, F. M. Potato Failures. (Two Reports.) Colo. Agl. Exp. Sta. Bullts. **70**: 1–20. 1902; **91**: 1–33. 1904.
Rolfs, F. M. (Tomato Diseases) *Corticium vagum* (B. & C.). Fla. Agl. Exp. Sta. Rept. (1905): 46–47.
Sorauer, P. Pflanzenkrankheiten (2d ed.), *l. c.*, 354–361.

A fungus causing important diseases of the potato and perhaps of a large number of other herbaceous and even woody plants has recently been placed under the name above given. The various

Fig. 217. Lettuce Seedlings attacked by Rhizoctonia

plant diseases due to this fungus had formerly been referred to the form genus Rhizoctonia, which is a genus established by De Candolle in 1815, including certain sterile fungi occurring upon the roots of plants. There are great difficulties in determining what might be considered species in forms which are referred to this form genus, and the Corticium stage has not yet

been studied in sufficient detail to be of much assistance. Nevertheless, there are certain characters of the mycelium by means of which it was believed to be possible more or less accurately to distinguish the Rhizoctonia from the mycelium of other fungi, or even with some accuracy to distinguish different species of Rhizoctonia, or sterile stages referred to the genus. It is only within the past four years that there has been found associated with the sterile mycelial form (the Rhizoctonia) this perfect stage, which has been determined as above given. It would seem probable, however, that we may look upon some of the rather diverse forms of Rhizoctonia as truly sterile stages of the Corticium mentioned.

Historical. In Europe the genus Rhizoctonia received considerable attention by the early mycologists, and various forms were described at some length by the Tulasnes (1851) and by Kühn (1858). Moreover, all the general texts on plant diseases have given some consideration to these forms. In the United States the *Corticium vagum* of Berkeley and Curtis was unknown, apparently, prior to 1904 as the cause of plant diseases, yet the fungus had been described as No. 262 of the North American fungi, occurring upon the bark of pine in South Carolina. In 1891 Pammel, in some notes on beet diseases, described a beet root rot, which he believed to be due to *Rhizoctonia Betæ* Kühn. From the mycelial characters of the fungus this was unquestionably a Rhizoctonia. Further, in 1892 a sterile fungus as a cause of damping-off in cotton was reported from Alabama (Atkinson), and later the same author described damping-off of various seedlings by a similar unnamed fungus at Ithaca, N.Y. Since 1898 the various plant diseases due to this fungus have received considerable attention in this country. Work at the Cornell and New York (Duggar and Stewart), Ohio (Selby), Colorado (F. M. Rolfs), Florida (F. M. Rolfs), and other experiment stations has demonstrated that the various forms of this fungus are extremely important as the cause of various types of plant diseases in this country.

Distribution and diversity of forms. The Rhizoctonia is unquestionably widely distributed in the United States and in Europe and Asia. In fact, wherever a careful study of plant diseases has been made, one or more forms of this fungus have been found,

and it is very probable that some of the damping-off which has been ascribed to Pythium could be properly referred to damage by this fungus. It is not possible at the present time to say definitely that such damping-off diseases as those of cotton, lettuce, etc., are produced by the same species or race of Rhizoctonia as that which is found upon the potato, but there is reason to believe that the differences which occur between the various forms of the parasite upon a large number of hosts are only such as might be considered varietal or racial, and in some instances we have unquestionably to do with physiological forms. It is certain, however, that *Rhizoctonia Medicaginis* De C. of Europe is a fungus very different from the common potato fungus of Europe and America and also from the common species producing damping-off of seedlings, rot of beets, etc., in this country. Moreover, a form which has been described (Duggar and Stewart) on rhubarb is likewise a very different organism. It would not, however, be surprising to find that a very large number of the other forms which have been discussed by various authors may be ascribed to one and the same species, the perfect stage of which would now appear to be *Corticium vagum* B. & C. var. *Solani* Burt.

FIG. 218. RHIZOCTONIA ON RADISH
(Photograph by H. H. Whetzel)

Effects upon the hosts. The fungus is perhaps most disastrous as a damping-off disease. The progress of the disease upon seedlings resembles very closely that of Pythium, and it is affected by similar conditions. The plants that have thus far seemed to be

most susceptible are such as lettuce (Fig. 217), sugar beet, celery, cotton, and the seedlings of various delicate, ornamental plants.

Upon the potato the fungus has been known for more than half a century in Europe, but largely through the presence of a sclerotial stage upon the tubers. This typical sclerotial stage

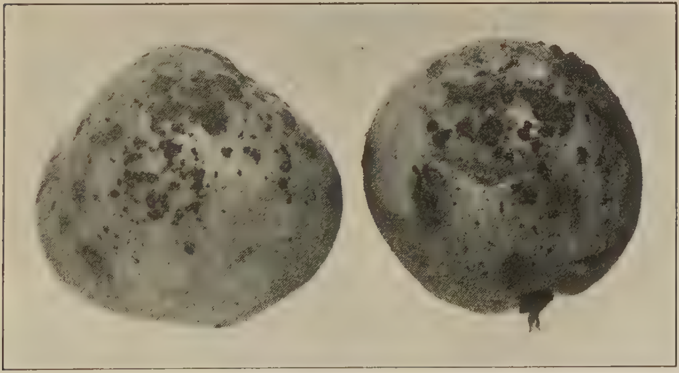


FIG. 219. RHIZOCTONIA ON POTATO: EUROPEAN (UPPER) AND AMERICAN (LOWER) SPECIMENS

has also been found abundantly in the United States during the past eight years, and it is unquestionably the same as the European form (Fig. 219). In this country, however, the Rhizoctonia was first found upon the stems of dying potato plants, and while it does not seem to be a very serious disease of potatoes, it is one

of some consequence. It is perhaps not responsible for all the injuries which have been ascribed to it in Colorado, particularly in so far as the production of the disease known as "little potato"

FIG. 220. RHIZOCTONIA PRODUCING A CROWN ROT OF BEETS

is concerned. The fungus, however, attacks the subterranean parts of the stem, as well as penetrating the roots, and the hyphæ are found, for the most part, enveloping stem and root, or distributed

within the pith. The sclerotia, which are formed upon the surface of the potatoes, do not seem to produce, in any case, rotting of the tissues below. They are closely adherent, but merely superficial, and perhaps serve particularly for the distribution of the fungus.

Upon the sugar beet this fungus produces, besides the damping-off already referred to, a characteristic form of rot. The leaves are affected at the bases, and these promptly wilt and decay. The fungus gains strength and penetrates into the superficial layers of the beet root, and frequently causes serious rotting, accompanied by cracking, as shown in Fig. 220.

In Europe *Rhizoctonia Medicaginis* has been found upon the beet, but that is a fungus very different from the Corticium, as subsequently mentioned. Moreover, *Rhizoctonia Medicaginis* has not been found in this country, although its hosts are such common plants as the asparagus, alfalfa, and sugar beet. Some of the various hosts upon which the forms of the Rhizoctonia allied to *Corticium vagum* var. *Solani* have thus far been found in America are as follows:

Sugar beet, *Beta vulgaris*,
Bean, *Phaseolus vulgaris*,
Carrot, *Daucus Carota*,
Cabbage and Cauliflower, *Brassica oleräcea*,
Cotton, *Gossypium hirsutum*,
Lettuce, *Lactuca sativa*,
Potato, *Solanum tuberosum*,
Radish, *Raphanus sativus*,
Sweet potato, *Ipomœa Batatas*,
Pumpkin, *Cucurbita Pepo*,
Watermelon, *Citrullus vulgaris*,
Garden pea, *Pisum sativum*, etc.,

as well as upon many species of ornamental plants and weeds.

Upon the tomato plant this fungus attacks also the subterranean parts of the stem and may be of importance where the soil is poorly aërated. It may also occur upon the fruits when these are in contact with the soil, but it is not probable that it becomes a fruit disease except when fruit has been previously injured in some manner. Upon either the potato or the tomato the fruiting stage may develop upon the stems above the surface of the ground to a distance of several inches.

Characters of the fungus. The mycelium varies considerably in form, depending upon age, or the conditions under which grown. In diseased tissues where there is abundance of water, or in pure culture, the young hyphæ develop branches, which are usually inclined at an acute angle to the direction of growth of the parent branch, although subsequently the two may grow parallel. The branch is usually somewhat narrowed or constricted where united with the main hypha, and a septum is formed at a distance of several micromillimeters from the point of origin of the branch. The hyphæ may be almost hyaline when young, but very generally become yellowish brown with age. Furthermore, in age the branches appear to be more at right angles, at least, so far as the origin is concerned. Upon many host plants, and especially when the fungus is grown in pure cultures, a short tufted growth of the mycelium may occur. The hyphæ of these tufts are brown, closely septate, constricted at the septa, and often branched in an irregular dichotomous fashion (Fig. 222, *b*). In the latter case the hyphæ readily break up into short hyphal lengths, consisting of a single cell or more, and these cells are able to germinate within a few hours when placed in fresh nutrient media. Germination is commonly by means of a germ tube protruded from a septum. A germ tube may even, in some cases, pass through a neighboring cell. It would appear that the fruiting stage usually develops upon living plants.

FIG. 221. RHIZOCTONIA ON BEAN STEMS AND PODS. (Photograph by M. J. Barrus)

In the case of the potato, it forms a membranous layer inclosing the stem for several inches above the surface of the ground. This layer is composed of rather loosely interwoven hyphæ, and on account of this character it is difficult to say if the plant is properly placed under the genus Corticium, or whether it might not with equal propriety be considered a species of Hypochnus. The basidia are short, cylindrical, or oblong, and apparently many

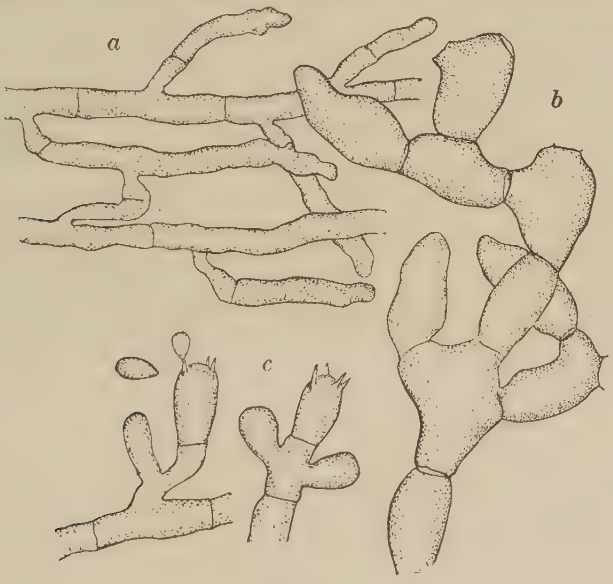


FIG. 222. *Corticium vagum* var. *Solani*

a, young hyphæ; *b*, cells from growth in tufts; *c*, basidia and spores

may be produced from a single parent hypha, each basidium being cut off from the hypha by a septum placed in the manner characteristic of the branching mycelium. The basidia bear four sterigmata and spores, although commonly only two may be observed at one time. The spores, according to Rolfs, are somewhat elliptical or irregular in outline, frequently obovate and nearly hyaline, $9–15 \times 6–13\mu$. Spore germination proceeds in ordinary nutrient media, and as a rule a septum is formed in the germ tube shortly after it emerges from the spore, the proximal portion of the germ tube being somewhat less in diameter. When produced

upon the majority of hosts the Corticium stage disappears by the time the host plant is dead.

A considerable amount of study is demanded in order that it may be determined what may properly be considered species or varieties within this group of plants. Cross-inoculation work is particularly important, yet it is also difficult, on account of the following fact: After being grown in culture for some time the fungus seems to change to a certain degree, at least, its relation to the host as a parasite, and it is possible that direct transference of the fungus from one host to another would not yield the same results as by the use of old cultures or cultures grown upon diverse media.

This fungus in all of its forms is readily culturable upon the ordinary nutrient media, such as bean stems, potato and beet cylinders, agars, corn meal, etc. It is, moreover, not difficult to make dilution cultures, even though the fungus usually grows upon those parts of the plant where bacteria would normally be present in abundance, as upon roots and underground stems. By carefully washing the mycelium in distilled water and then by the use of acidulated media, as suggested under cultural methods, the fungus may be readily separated from contaminating bacteria.

Control. No effective preventive measures for the forms of this fungus have yet been found. It would appear, however, that general sanitary precautions are important. Good drainage in the upper layer of the soil and the presence of a layer of sand, charcoal, or cinders serve in great measure to prevent the appearance of the fungus. An aërated soil is also less liable to be seriously affected, owing, perhaps, to the better health of the roots than one which is poorly aërated. The application of lime and other fungicidal mixtures to a soil is commonly useless. This fungus is apparently not readily affected either by weak alkalis or acids; but since acid conditions render the host more susceptible, liming has value.

V. HEART ROT OF SUGAR MAPLE

Hydnum septentrionale Fr.

Atkinson, Geo. F. Geological Survey of La. (1889): 335–336. *pl. 58.*

Among the numerous species of the genus Hydnum, which embrace the commoner toothed Basidiomycetes, it would seem

that few may be classed as true parasites, the majority growing upon logs, stumps, etc., after death, or after being felled. Some, however, are unquestionably in part parasitic to the extent that they may be considered disease-producing in woody plants.

This species occurs extensively in the United States, principally on the sugar maple (*Acer saccharum*), but also on other species of deciduous trees. It is likewise found generally distributed in Europe. The effects of this fungus upon the wood of diseased trees has not been carefully studied, but there is certainly a heart decay, probably more or less in the manner of some of the diseases subsequently described.

The sporophores appear in bracket-like clusters, which may be 20–30 cm. wide and 50–80 cm. or more in longitudinal extent. The general color is creamy white, and the texture at first fleshy, becoming more fibrous. The pileus, often 3 cm. thick, presents an almost plain upper surface, slightly scaly, all of the pilei being united posteriorly. Teeth slender and often 12 mm. long. This is one of the largest fungi in this genus, and it is striking in appearance.

A number of species of this genus, or species of closely related genera, particularly the resupinate forms, are found upon dead and decaying wood. More beautiful and structurally differentiated of the Hydnaceæ, such as *Hydnum erinaceus*, *Hydnum coralloides*, etc., are also found upon dead logs and trees and sometimes even upon decayed portions of living trees.

VI. WHITE ROT OF DECIDUOUS TREES

Polyporus squamosus (Huds.) Fr.

Buller, A. H. R. The Biology of Polyporus squamosus Huds., a Timber-destroying Fungus. Journ. of Economic Biology **1**: 101–138. *pls. 5–9.* 1906.

The great scaly Polyporus, sometimes known as the Saddle-back fungus, is a tree-destroying parasite whose conspicuous bracket sporophores are in many regions well known upon ornamental, shade, and forest trees. The fungus occurs throughout a large portion of Europe, but it has been found as yet only sparingly, it would seem, in the northern portion of the United States. The

distribution of this fungus, however, is doubtless much more extensive, although the indications are that it is uncommon in regions which are rather dry throughout the summer.

The sporophores of this fungus have been reported upon various species of maple (Acer), oak (Quercus), elm (Ulmus), basswood (Tilia), willow (Salix), ash (Fraxinus), etc.; therefore it may be expected upon practically any of the deciduous trees. There seems to be no record of its occurrence upon conifers. The tree attacked

FIG. 223. *POLYPORUS SQUAMOSUS*, LOWER SURFACE. (After Buller)

by this fungus dies gradually, and the effect may in general be called a white rot, since there is no marked discoloration, and the presence of the mycelium is to lighten rather than darken the effect. The hyphæ probably obtain entrance through wounds, as is the case with most other related fungi. The mycelium then grows upward and downward, first in the central portion of the tree, apparently having little power to affect directly the living portions. It gradually works and spreads outward, killing the young wood doubtless prior to invasion, and finally breaking through the surface and producing sporophores after a period of years.

The hyphæ are hyaline, considerably septate, and often show clamp connections when growing in the vessels. They grow more quickly in the vessels, but are not ultimately assembled into strands in these parts. The wood is eventually separated into plates or cuboidal areas, and the texture of the wood becomes light and corky. The separation of the wood into plates is accomplished by the growth of white strands or bands of the mycelium in all three directions, that is, radially, tangentially, and longitudinally. The wood elements, which gradually disappear under the solvent action of

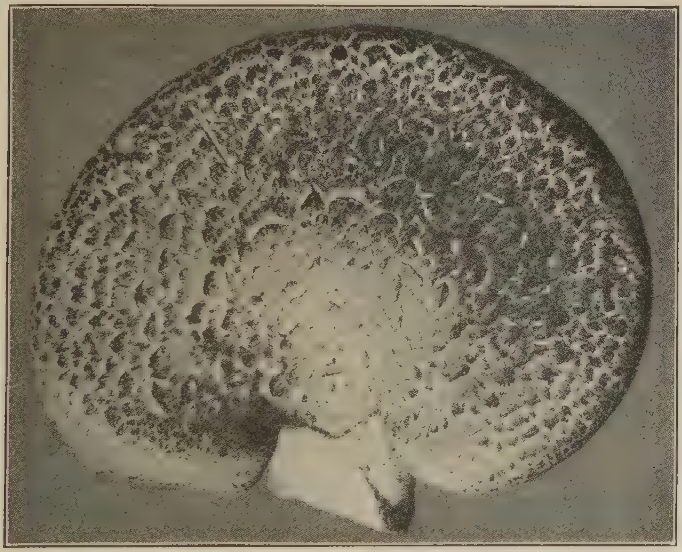


FIG. 224. *POLYPORUS SQUAMOSUS*, UPPER SURFACE

the fungus, are largely those which are less lignified, such as the fibers between the vessels, that is, those usually produced only during spring growth. In the dissolution of the cells, first the contents, next the secondary cellulose layer, and finally the middle lamellæ disappear, so that during the process the cells do not become separated in the early stages of decay.

The mycelium unquestionably possesses a variety of enzymes. According to Buller, "from an enzymotic study of wood undergoing decay from the agency of *Polyporus squamosus* evidence was taken that various enzymes are excreted by the fungus mycelium. Thus

the disappearance of starch, proteids, and cellulose suggests that the fungus produces amylolytic, proteolytic, and cyteolytic enzymes." A direct study of this point was attempted by making extractions from fresh, young fruit bodies, and testing these. While this may not be an absolute criterion for the basis of an opinion as to the enzymes produced in the mycelium, it is nevertheless interesting that laccase, tyrosinase, amylase, emulsin, protease, lipase, rennetase, and coagulase were seemingly present, "whereas negative results were obtained in the tests for pectase, maltase, invertase, trehalase, and cytase. However, a study of the destruction of wood by the fungus furnishes evidence that the mycelium produces cytase and possibly hadromase."

FIG. 225. *Polyporus squamosus:* Progressive Destruction of Wood (After Buller)

The sporophores arise singly or in clusters of a few brackets, usually during summer and early autumn. It requires but a brief period for these sporophores to attain their growth, brackets measuring 15–25 cm. in width having been observed to complete growth within two weeks. The mature sporophore is yellowish brown above, and the surface of the cap is thrown into characteristic brown scales. The plants are commonly 15–30 cm. broad, although one specimen measuring 65 cm. and weighing approximately six and a half pounds has been found (Buller). The margins of the pileus are slightly revolute even on maturity, the lower surface of the pileus yellowish, with pores at first small, later expanding, and angular.

The flesh is white and soft when young, becoming tough with age. Nevertheless, this sporophore persists but a single season, while a diseased tree may continue to produce sporophores throughout a period of years, and even for some time after having been felled.

In the development of the sporophore a knob-shaped, fleshy body appears, from which may arise one or more short stems, and the changes in one of the latter are usually about as follows: An apical depression is the first evidence of the pileus. Further growth in the stem is hyponastic, raising the depression toward the horizontal, and at the same time there is rapid and distinctly one-sided lateral expansion, and later, thickening in the region of the depression, so that it becomes a definite pileus, with the greatest growth on the sides farthest from the axis of attachment, thus eventually giving the excentric or almost lateral type of sporophore.

The hymenium is very early differentiated, first as very shallow reticulations, but a downward growth of the netted ridges develops in time the relatively deep pores of the mature sporophore (Fig. 223). The basidia and spores are not unusual in form. The latter measure about $12 \times 5\,\mu$. It is not without interest to note that the spores are forcibly thrown from the sterigmata in this species, and doubtless in practically all other species of Basidiomycetes, the form of the sterigmata and the attachment of the spores to these frequently suggesting the possibility of well-regulated tensions. By a comparatively accurate method Buller estimated the number of spores produced in a single pore, and found it to be about one million, seven hundred thousand. The spores, like those of mold fungi, will withstand immersion in water for a long period.

VII. DECAY, OR BROWN ROT, OF TREES

Polyporus sulphureus (Bull.) Fr.

Atkinson, Geo. F. Studies of Some Shade Tree and Timber Destroying Fungi. Cornell Agl. Exp. Sta. Bullt. **193**: 208–214. 1901.

Schrenk, H. von. Polyporus sulfureus (Bull.) Fr. Div. Veg. Phys. and Path., U. S. Dept. Agl. **25**: 40–52. *pls. 11* (in part), *13*. 1900.

The sporophores of no other fungus present, probably, a more striking appearance than the fresh, vigorous, sulfur-yellow cluster of the above species. It cannot be considered a very virulent disease-producing organism, in spite of its wide distribution and

the variety of host plants upon which it is reported. This fungus has been found practically throughout the world where trees grow. It is unquestionably more abundant in humid climates, yet minor or nonpersistent, unfavorable conditions do not readily affect it.

This Polyporus is of special interest because of its occurrence upon a large variety of trees. Deciduous trees are more commonly attacked, yet both in Europe and America it is not infrequently found upon conifers. It is perhaps oftener noticed upon such

FIG. 226. *POLYPORUS SULPHUREUS* ON EXPOSED ROOTS OF A LIVING TREE
(Photograph by L. H. Childers)

forest and shade trees as oak, walnut, butternut, ash, black locust, poplar, and willow. Among orchard trees the cherry in old orchards is a common host, but pear and apple trees are also susceptible. Moreover, the sporophores of this fungus may appear upon fallen trunks and stumps, and it appears to be true that the mycelium of the fungus may develop extensively in fallen trunks.

The coniferous trees upon which it has been more frequently observed are the larch in Europe and the hemlock and spruce in America.

The mycelium evidently establishes itself in a saprophytic manner upon dead branches or in the decayed wood about knot holes, thence gaining entrance to the heartwood of the main trunk. After growing for years in the latter, it may develop sporophores

FIG. 227. *POLYPORUS SULPHUREUS* ON WHITE OAK, SHOWING NATURE OF DECAY. (Photograph by Geo. F. Atkinson)

where wounds occur, permitting the vigorous mycelium to reach the surface readily. In other cases the path of the mycelium of this fungus evidently extends directly to the surface, killing the wood as it progresses. Sporophores may then be developed on the otherwise uninjured bark surface. In general, the growth of the mycelium causes a prompt decay of the wood, the latter becoming

brown and, to a considerable extent, separated into plate-like areas, corresponding in their radial diameters to the seasonal wood rings. These plates are subsequently broken into smaller areas by lateral contact, and in all of the clefts thus formed by the processes indicated, the mycelium often grows (especially in deciduous trees) in sheath-like strata, the particular appearance of the mycelium, however, being modified in different hosts, largely depending upon the density of the wood (Fig. 227). In all cases the wood is brittle in the last stages of decay and may be readily reduced to a powder.

According to von Schrenk the detailed changes induced in the wood of the spruce may be stated as follows:

Minute changes in the wood.[1] The minute changes which the mycelium of *Polyporus sulfureus* induces in the wood cells are such that they cannot be mistaken. It has been mentioned that the annual rings break into bands which curve inward as the process of drying goes on. A tangential view of several of these bands before they have broken will present an appearance such as is shown on Pl. XI, fig. 4. A large number of fissures have formed both across the wood fibers and parallel with them. The latter are more prominent — the cross fissures never occurring alone, but generally connecting several longitudinal fissures. It will be noted that the breaks are characterized by sharp right angles, and in many places a stepladder arrangement is evident. In the early stages of attack the wood fibers turn red-brown and shrink. As a result, fissures are formed in the walls of the tracheids, which extend diagonally across the wall at an angle of approximately 45 degrees. (Pl. XI, fig. 1). The medullary ray cells are at this point still intact, and hold together the more or less brittle wood fibers. The next stage in the decomposition consists in the absorption of the medullary rays. This allows the wood fibers to contract more than up to that time, and as a result breaks occur. These breaks form at first so as to connect adjacent cavities left by the absorption of the medullary rays. The wood fibers tend to curve in one direction or another and break at the weakest point, namely, between two cavities, where the opportunity for curvature is greatest. What determines the direction of curvature of the wood fibers has not yet been explained. In the illustration the curvature is toward the right. This curving has the effect of bringing medullary rays which are in different longitudinal rows approximately into a line. Thus at "a" two cavities are shown which are separated by a curved fiber which sooner or later will break, uniting the two. At first two ray cavities are joined, then more, until long longitudinal holes are formed, such as are shown in fig. 4 of Pl. XI. The reason for the sharp edges is now very apparent, likewise why these fissure figures appear only on a tangential view, while on the radial view one simply sees the fissures as lines extending at right angles across a ring of wood (Pl. XIII).

[1] The plates referred to are also those of von Schrenk's bulletin.

On the oak and other deciduous trees the mycelium is much more dense than in the spruce, for example. In the latter the mycelium is said to be colorless. It is, however, in some instances, slightly cream colored when approaching the surface. Hartig has mentioned the appearance of a secondary fruit form in the oak. This also occurs upon other hosts, and cultures from fragments of the sporophore have promptly given, on various culture media, a vigorous cream colored mycelium, which with age becomes mealy in appearance, due to the extensive formation of conidia, such as are referred to above. These conidia correspond to those which are considered by Brefeld to be the typical oidial stage frequently present in Hymenomycetes.

The sporophores of this species appear usually during the late summer or early autumn, in large, shelving clusters (Fig. 226) or sometimes scattered. The form of the pileus may be considerably modified by its position upon the host and by its relation to other sporophores. The sporophore is fleshy and of a cheese-like consistency when young, becoming harder and woodier with age. At first the entire sporophore is yellow, but later the under, pore-bearing surfaces are bright yellow, while the upper surfaces are ordinarily orange-red. The flesh is at first white, becoming slightly cream colored with age. These sporophores may grow in such masses as to attain a length and height of from 30 to 40 cm. The individual pilei may be entirely sessile or slightly stalked, and loosely scattered or so closely massed as to be united in the vicinity of the host. The young plants have a distinct odor, which becomes pronounced with age. The pores are found on the under surface only. They are about 4 mm. deep, with nearly circular outlines. The spores are hyaline, ovoidal in outline, and usually measure $7-8 \times 4-5\,\mu$.

Control. In controlling this fungus the only practical measures are to cover up as promptly as possible with tar or other antiseptic materials all wounds, either natural or as a result of pruning, and further, to destroy all sporophores as they appear. The spores develop very quickly after the sporophores are mature, and it is very probable that their distribution is effected by means of insects, which may be attracted by droplets of a sugary substance which may accumulate on the under surfaces of the sporophores.

VIII. POLYPORUS: OTHER SPECIES

In addition to the species described at length, the following may be mentioned also as among those of special importance,

FIG. 228. *POLYPORUS BOREALIS* ON LIVING TSUGA. (Photograph by Geo. F. Atkinson)

occurring in Europe and in America, which have received more or less recent consideration from the standpoint of shade and forest tree diseases.

Polyporus borealis (Wahl.) Fr. is a characteristic and destructive disease of the spruce in Europe, and it occurs on a variety of conifers in America.[1] The bracketed sporophores are clustered, as shown in Fig. 228. They are fleshy for some time, but finally tough and dry. The spores are minute, measuring $4-5 \times 3\,\mu$. The mycelium develops abundantly in the wood with typical markings (Fig. 229).

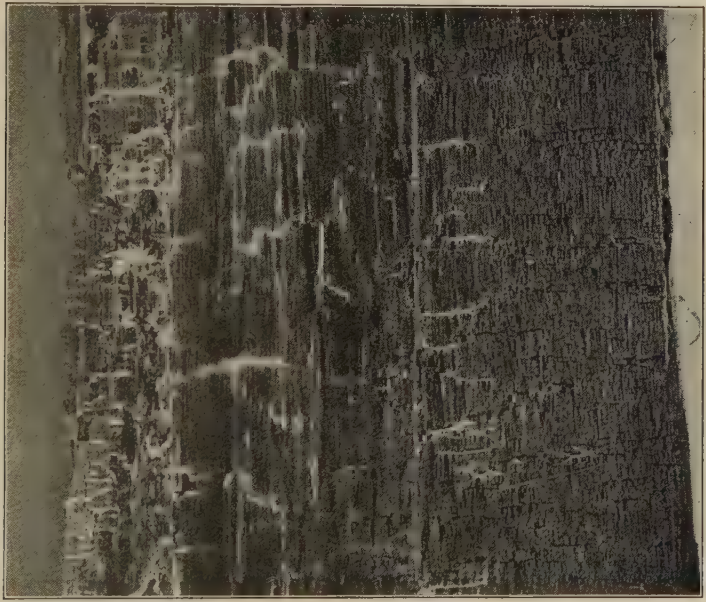


FIG. 229. *POLYPORUS BOREALIS:* LONGITUDINAL SECTION OF LOG, SHOWING MYCELIUM. (Photograph by Geo. F. Atkinson)

Polyporus carneus Nees causes a red rot, or peckiness, in the common red cedar (*Juniperus virginiana*) and in the southern red cedar (*Juniperus barbadensis*), as well as in other conifers.[2]

Polyporus Juniperinus von Schrenk is apparently the cause of the white rot of the red cedar.[2]

Polyporus Schweinitzii Fr. is abundant in Europe on the Scotch pine, Weymouth pine, and the larch.[3] This species is yellowish

[1] Atkinson, Geo. F. Cornell Agl. Exp. Sta. Bullt. **193** : 202–208. 1901.

[2] Schrenk, H. von. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **21** : 1–22. *pls. 1–7.* 1900.

[3] Schrenk, H. von. Div. Veg. Phys. and Path., U. S. Dept. Agl. Bullt. **25** : 18–24.

white, with little or no stipe, yellowish green pores, and spores $7\text{–}8 \times 3\frac{1}{2}\,\mu$.

Polyporus Betulinus (Bull.) Fr. is the cause of a sapwood decay in several species of birch, and it is very widely distributed.

Polyporus Fraxinophilus Pk., a rather small white form with pileus $5\text{–}10 \times 2.5\text{–}4$ cm., produces an important disease in the white ash (*Fraxinus americana*).[1]

IX. FOMES

Atkinson, Geo. F. Studies of Some Shade Tree and Timber Destroying Fungi. Cornell Agl. Exp. Sta. Bullt. **193**: 199–235. *figs. 56–94.* 1901.
Schrenk, H. von. Diseases of Deciduous Forest Trees. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **149**: 1–85. *pls. 1–10.* 1909.

Fig. 230. *Fomes fomentarius* on Dead Beech. (Photograph by Geo. F. Atkinson)

The genus Fomes includes among its representatives the most destructive forest-tree organisms in this order of fungi. The conspicuous bracket-like and hoof-shaped sporophores are familiar to all who have given the typical, temperate moist forests any attention. They are, for the most part, moisture-loving, wound fungi; and, consequently, they find in the conditions of the forest the opportunity for their maximum destructiveness. They may be entirely absent from shade and meadow trees. Among many species of common occurrence, special mention should be made of *Fomes igniarius*, *Fomes fomentarius*, and *Fomes Pinicola*. *Fomes applanatus* is

[1] Schrenk, H. von. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **32**: 1–18. *pls. 1–5.* 1903.

FIG. 231. *Fomes pinicola* ON DEAD HEMLOCK. (Photograph by Geo. F. Atkinson)

also a conspicuous form. Under the conditions now necessarily confronting those interested in forestry, there is no practical method of control. In the woodlot these fungi will prove far less serious.

Fomes igniarius (L.) Gillett. This species, commonly known as the false tinder fungus, occurs upon a great variety of deciduous

FIG. 232. *Fomes applanatus* on Hard Maple: Small Specimens
(Photograph by Geo. F. Atkinson)

trees. In the moist forest it is often difficult to find a beech tree (*Fagus grandifolia*) ten inches or more in diameter which is not seriously affected. The fungus is also destructive to hard maple (*Acer saccharum*), yellow birch (*Betula lutea*), aspen (*Populus tremuloides*), and certain oaks (*Quercus* spp.) in their ranges.

The sporophore varies in form from the shape of a hoof to that of a thick bracket. The upper surface is, with age, black, indurated, and cracked, also showing concentric ridges; while the lower surface is commonly, during the growing season, cinnamon-brown. The mycelium grows within the heartwood, which is generally converted to a soft mass, bordered by black rings.

Fomes fomentarius (L.) Fr. This fungus occurs in situations similar to those mentioned for the preceding organism. It is far more common upon beech, yellow birch, and hard maple. The sporophores may be found upon living trees, but they are produced in far greater abundance after the death of the tree affected. They are distinctly hoof-shaped (Fig. 230), with a grayish upper surface and a lower surface which is light brown or gray-brown during the summer.

Fomes Pinicola Fr. In the moist temperate regions this fungus induces a decay in a variety of conifers, especially pines (*Pinus* spp.), spruces (*Picea* spp.), and balsam (*Abies balsamea*). The sporophore is a broad, relatively thick bracket, with a creamy white under surface. The upper surface is dark, generally with broad ridges, the lower of which may be reddish to bright red-brown in color (Fig. 231). The sporophores generally develop after the death of the tree.

Fomes applanatus (Pers.) Wallr. The sporophores of this fungus constitute the most conspicuous forest brackets. The fungus occurs upon a variety of deciduous trees, but it is regarded as more commonly saprophytic. In any event, it is important in the decay of trees injured by fire or water, and of fallen trunks.

X. A BROWN ROT OF CONIFERS

Trametes Pini (Brot.) Fr.

Hartig, R. Trametes Pini Fr. Wichtige Krankheiten der Waldbäume. pp. 43–61. *pl. 3. figs. 1–19.* 1874.

Among the various species assigned to the genus Trametes there are some important wood-destroying fungi. *Trametes Pini* is common in the United States throughout the coniferous forests. In the Ozark pine forests of Missouri it is the chief cause of loss from fungi. In some regions which have been cut over there have been left thick forest groves, and these often consist very

largely of trees that are affected by this "punk." The fungus is also common in pine forests of northern Europe, occurring there, as well as in parts of America, on the spruce. According to Hartig, trees are more subject to this fungus in woods exposed to strong winds, since the breaking of limbs of older trees by any cause invites infection.

The phenomenon of infection and the spread of the fungus within the tree are doubtless accomplished in a manner similar to the cases already described. The wood pervaded by the fungus assumes from the first a deep red-brown color. There is no checking, in the proper sense, although occasionally the annular rings may in one or more regions be readily separable. The chief characteristic, however, so far as the effect upon the wood is concerned, is to be found in the development of bleached pits or pockets. The formation of these may be readily understood when it is ascertained that the action of the mycelium is first to delignify the cells, then to dissolve the middle lamellæ, so that the cells are set free prior to general dissolution. The wood is therefore in certain areas transformed to more or less pure cellulose and consequently bleached in appearance. The pockets appear more or less circular in cross section, and vary in shape from ovoidal to long-cylindrical. The pockets are at first to be found chiefly in the spring wood portion of the annular ring. The mycelium is yellowish in color and is not massed in strands in the pockets.

In the pine the sporophore is almost invariably formed in a wounded area, and the fruit body may be in the form of an incrusted, brown-black stratum, or as a hoof-shaped bracket. These sporophores are perennial, and for a few years the annular layers which are developed successively upon the fruiting surfaces increase the size of the fruit body. Subsequently, however, there may be no increase in size from the deposition of new layers, or the strata may be of smaller extent, in case of the death of a portion of the last-formed annular layer. The fruit body may attain a considerable age, and each year or season of growth will be outlined by a somewhat prominent concentric ring, or surface ridge. The lower or marginal ridge, including the hymenial surface, is of a light brown color, but older ridges become black and very irregular in outline. A section of a sporophore shows a layered structure,

corresponding to the surface rings. The new growth apparently takes place from all exposed surfaces which are still corky in texture, including the lower margins of the sporophores. Doubtless the sterile basidia continue their growth as vegetative hyphæ. The sporophores may be produced high upon the trunks, and since an annual crop of spores is produced, they are most favorably situated to be blown upon other trees. Young conifers are in part protected from infection by the resinous exudates which form over wounds.

Control. No method of controlling this fungus is possible, except by preventing, as far as may be, the causes leading to the breaking of living branches. In well-cared-for forests it is practicable to fell diseased trees as promptly as possible or to destroy developing sporophores.

XI. ROOT DISEASE OF SUGAR CANE

Marasmius plicatus Wakker.

Cobb, N. A. Fungus Maladies of the Sugar Cane. Hawaiian Sugar Planters' Exp. Sta., Div. Path. and Phys. Bullt. **6**: 110 pp. (cf. 24–26, 50). 1906.

Fulton, H. R. The Root Disease of Sugar Cane. La. Agl. Exp. Sta. Bullt. **100**: 1–21. *figs. 1–8.* 1908.

Howard, A. On Some Diseases of the Sugar Cane in the West Indies. Ann. Bot. **17**: 373–411. *pl. 18.* 1903.

Wakker, J. H. Eine Zuckerrohrkrankheit, verursacht durch Marasmius Sacchari n. sp. Centrbl. f. Bakt., Par. und Infektionskr. **2** (Abt. 2): 44–56. *figs. 1–5.* 1896.

A root disease of the sugar cane in Java was first described by Wakker, and the causal fungus was given as *Marasmius Sacchari*. A similar disease was subsequently found in other portions of the West Indies, in the Hawaiian Islands, and recently in Louisiana. It is now known to be widely distributed in the southern United States. From the work which has been done thus far it seems apparent that several species of Marasmius may be concerned in the production of a more or less common type of root disease. In all cases the fungus appears to be merely a weak parasite, and it frequently gains entrance to the host through the wounds upon cuttings and seed plants.

Symptoms. Stools of the sugar cane affected by this fungus are commonly smaller and poorly rooted, so that the disease becomes especially evident during conditions of drought.

Having gained entrance through the stubble or plant canes the fungus invests the root system, and also the lower joints of the stem, cementing the leaf sheaths together near the base with a whitish mycelium. Not only is great injury done to the growing stools, but a vastly greater loss results from missing hills of cane, on account of the fact that the diseased stubble, or plant canes, may be so covered up by the fungus that few stalks will be produced.

FIG. 233. *MARASMIUS PLICATUS* ON SUGAR CANE. (Photograph by H. R. Fulton)

The fungus. Under favorable conditions (constant moisture being indispensable), the mycelium which is constantly associated with the root disease may develop fruit bodies, or sporophores. The type of sporophore in the case of the Louisiana disease is shown in Fig. 233. It is described by Fulton as follows:

The pileus is dirty white, becoming somewhat darker with age; it is usually about three fourths of an inch in diameter, but may attain a size of an inch and one fourth. When young it is convex, and at maturity is almost flat or perhaps slightly concave. Its surface is smooth. On the under side are the radiating gills which have an even, thin edge, and a straight, radial direction. The long gills extend from the margin to the stem, and are attached to the stalk itself rather than to a prominent ring about the stalk. Other shorter gills extend from the margin just far enough to fill in the angles between the longer gills. The stipe is about equal in length to the diameter of the cap, or in some cases somewhat less. It usually arises from the side of the leaf sheath, and is somewhat curved so as to bring the cap into a horizontal position. It is normally attached to the cap at its central point, but at times this attachment is somewhat eccentric. The stipe is smooth externally, except at the base, which is downy and also enlarged. The whole fruit cap persists for about a day, and then gradually dries, losing its form, but not undergoing immediate disintegration.

The spores, white in mass, are hyaline, ovate, averaging 6–8 × 5–6 μ, with a prolongation at the base. The fungus has been grown in pure cultures, and inoculation experiments from such pure cultures have yielded the typical disease, this in turn showing the characteristic mycelium. The mycelium in culture makes the best growth at from 25° to 30° C. The fungus spreads rapidly by means of the vigorous mycelium, and the sporophores are produced so infrequently that spores would seem to play a minor part in the distribution of the species.

Control. As a result of his studies, Fulton cites the following conditions as favoring the growth of the organism.

1. Slowness of germination and early growth of the canes.
2. Improper cultural procedures.
3. Unsuitable soil.
4. Bad drainage.
5. Unfavorable seasonal conditions.
6. A stubble crop.

These facts make it evident that prevention should be concerned with general methods of sanitation, such as the destruction of all infected waste material, the rotation of crops, selection and disinfection of seed cane, and also the planting of the more resistant varieties.

XII. ROOT ROT OF FRUIT TREES

Clitocybe parasitica Wilcox

WILCOX, E. M. A Rhizomorphic Root-Rot of Fruit Trees. Okla. Agl. Exp. Sta. Bullt. **49**: 1–32. *pls. 1–11.* 1901.

For some years attention has been called to a destructive disease of apple trees in Missouri, Oklahoma, and adjacent states, characterized primarily by the death of the root system. There is commonly associated with this disease an invasion of the root system by the mycelium of some one of the mushrooms. Wilcox has concluded that the disease in Oklahoma is caused by a fungus described as a new species, *Clitocybe parasitica*. He has found this fungus constantly associated with the root rot of the apple, and also with a similar disease of peach and cherry, as well as of certain native species of oak. Other observers have apparently not been able to conclude that a Clitocybe is the cause of the disease prevalent

throughout that general region, and now notably destructive in sections of Missouri. At any rate this species of Clitocybe is very common at least from Missouri southwestward, and occurs abundantly in regions in which the root rot of apples is unknown. This fungus occurs, for instance, during a favorable season in unlimited quantity at Columbia, Mo., and may be found arising in large clusters from the roots of hickory and other deciduous trees; but no evidence in that vicinity of its appearance in orchards has come to the attention of the writer, although constant search has been made for it, particularly where orchards have succeeded

FIG. 234. *CLITOCYBE PARASITICA:* A CLUSTER OF SPOROPHORES FROM ROOT OF HICKORY

deciduous forests. The Clitocybe is unquestionably, however, an injurious fungus, and it is quite possible that the failure to attack apples in certain regions is due to more favorable conditions for the host.

The fungus shown in Fig. 234 grows in very dense clusters. The pileus is usually from 6 to 8 cm. in diameter, convex or umbonate in form, usually beset with minute scales, varying in color from mottled buff to pale yellowish brown. The gills are paler and become mottled, noticeably decurrent at first, which character is still slightly evident with age. The stipe is usually 10–16 cm. in length, and up to 1 cm. in diameter, solid, usually curved, and

somewhat darker in color than the pileus. Rhizomorphs are present, and these, at maturity, are black in color. When growing close beside the trunk or under the edge of fallen logs or brush, giant forms of the mushroom may appear, single specimens of which have been found weighing more than a pound, with gills anastomosing and variously modified. It has been suggested by some observers that *Agaricus melleus* is responsible for this root rot of the apple, but the writer has never detected this fungus associated with the typical disease in Missouri.

Control. It is hardly possible to adopt effective control measures, but it is desirable that every means possible be taken to get rid of stumps and roots in land set to an orchard, and preferably such land should be grown to some grain or other field crop for several years previous to its use for orchard purposes. Isolation of affected trees by trenching, and the prompt removal and destruction of these, is also to be recommended.

XIII. THE HONEY AGARIC

Armillaria mellea Vahl.

HARTIG, R. Wichtige Krankheiten der Waldbäume. pp. 12–42. *pls. 1, 2.*
HARTIG, R. Die Zersetzungserscheinungen d. Holzes d. Nadelholzbäume u. d. Eiche. Berlin, 1878.

Of the Agaricaceæ which may induce plant diseases there is no fungus better known or more destructive than *Armillaria mellea*. It is abundant in Europe and America, and doubtless has a very general distribution. This fungus is unusual in that it is no less common as a saprophyte than as a parasite. It is said to occur upon all conifers which grow in Europe, and, among deciduous trees, especially upon *Prunus avium* and *Prunus domestica*. In moist regions it has been noted upon a variety of hosts, and in the small forests of central Missouri it has done greatest damage to young trees of the hop hornbeam (*Ostrya virginiana*) and of the white oak (*Quercus alba*). It frequently attacks saplings, or at least its effects become evident upon such trees, of from $1\frac{1}{2}$ to 3 in. in diameter. Infested trees grow very slowly, and often the leaves fall in early summer. When so far affected death promptly ensues. An examination of the crown of these trees would show

a considerably advanced stage of decay in the region of the cambium, including both wood and bark. There is present an abundant white mycelium and very characteristic mycelial strands, as subsequently described.

The abundant, white mycelium is particularly rich in stored nutrients. It commonly extends several feet above the crown, mostly between the wood and bark. The characteristic mycelial cords, by which this fungus is best known, are shining, gray-black

FIG. 235. *ARMILLARIA MELLEA* ON A STUMP OF WHITE OAK
(Photograph by Geo. F. Atkinson)

strands which may measure from 1 to $2\frac{1}{2}$ mm. in diameter. They are typical rhizomorphs. These begin as complex hyphal masses which become readily sclerotial in character. These strands attain enormous lengths. They may course upward and downward in the affected tree, generally under the bark, or merely in close contact with the outer surface of the bark. They also grow through the soil to considerable distances, thus serving to spread the disease to neighboring trees. According to Hartig this strand is differentiated near the apex into several layers. The outer, more gelatinous layer becomes somewhat horny; some loose hyphæ, however,

extend outward, perpendicular to this sheath. Within this zone there is next found a dense, resistant layer of small-celled pseudo-parenchymatous tissue, surrounding a medullary cylinder composed of lighter, more delicate, conducting cells. At the base of the tree the general mycelium produces a definite white rot.

In this country sporophores are usually produced during favorable weather in September, October, and early November. They may appear at the collar of the tree, or upon the roots, etc. Moreover, a year or two after forest land has been cleared for pasturage, the sporophores may appear in enormous quantities on the slightly sunken roots. These fruit bodies are usually produced in clusters,

FIG. 236. *ARMILLARIA MELLEA* ON EXPOSED ROOTS IN A MEADOW

arising either directly from a felted mycelium or from rhizomorphal aggregations. The mature sporophore (Fig. 236) consists of a fleshy cap, ordinarily 5-15 cm. broad, borne upon a central stalk often 12–18 cm. long, with cartilaginous rind and spongy center. The stem is yellowish in color above, but usually brown below, with a more or less persistent annulus, or attached collar. The cap varies from convex to slightly umbonate. It is yellow to orange-brown in color, the center of the cap when younger being often covered with papilliform, brown, or sooty scales. The lamellæ are white or slightly discolored, distinct one from another, and somewhat decurrent upon the stem. In taste this plant is distinctly acrid, sometimes very harsh. It is, however, considered to be edible by those who have developed a taste for a variety of mushroom flavors.

With reference to the development of the sporophore, the early studies of Hartig would indicate that it begins as an ovoidal or spheroidal body, made up of closely united hyphæ, the direction of whose growth is soon mostly longitudinal. For some time there is no differentiation of stem and cap, but after the hyphal mass has attained a length of several millimeters, differentiation into these parts becomes evident. In the first place, an annular furrow is formed by cessation of growth in certain filaments near the apex, and this annular furrow delimits pileus and stipe. Subsequently,

FIG. 237. *ARMILLARIA MELLEA:* RHIZOMORPHS AND YOUNG SPOROPHORES (Photograph by H. H. Whetzel)

the outer layer of filaments from below and from above this furrow become interlaced, and thus is formed an early stage of the veil, or membrane, inclosing the area in which the hymenium is eventually produced. As growth proceeds, the overlapping peripheral elements become wholly indistinguishable, the pileus is then developed by successions of epinastic and hyponastic growth, the principal growth being in the direction of the pileus. The hymenial surface is thereafter differentiated by the growth downward of alternating radial hyphal bands, which form the trama, or middle tissue of the lamella, bearing eventually the hymenium or surface from which the basidia are produced. With the rapid growth in

the lower, or lamellar, portion of the pileus, the cap is quickly raised and the veil broken at the margins of the pileus, with the gradual expansion of the upper portion of the plant. This general form of development apparently maintains in most angiocarpic Agaricaceæ

FIG. 238. *ARMILLARIA MELLEA*: BASIDIAL SURFACE. (After Hartig)

which possess a veil only. Differences occur, however, with regard to the time of differentiation, position of the forming lamellæ, the stem, veil, etc.

XIV. EUROPEAN ROOT DISEASE OF ALFALFA AND OTHER PLANTS

Rhizoctonia Medicaginis De C.

FRANK, A. B. Die Pilzparisitären Krankheiten der Pflanzen, *l. c.*, pp. 514-51?
KÜHN, J. Die Krankheiten der Kulturgewächse, *l. c.*, p. 245.
TULASNE, L. R. and C. Rhizoctonia. Fungi Hypogæi, *l. c.*, pp. 188–195.

De Candolle described accurately the root disease of alfalfa (*Medicago sativa*) in 1815, and gave to the violet fungus producing the disease the name above indicated. The fungus had previously passed under another name, which, however, probably referred to several diverse species. From the subsequent work of Kühn, Frank, Comes, and others, much additional information has been presented concerning this fungus. Many, however, have regarded it as closely related to certain sterile fungi found upon the crocus, potato, cabbage, sugar beet, and many other cultivated

and wild plants. The last-mentioned fungi are at least closely related, perhaps forms of a single species; and in this treatise they are provisionally referred to the genus Corticium. They have been discussed under *Corticium vagum* B. & C., var. *Solani* Burt.

FIG. 239. *RHIZOCTONIA MEDICAGINIS* ON ROOTS OF ASPARAGUS

The writer examined various diseases due to Rhizoctonia while in Europe during 1899 and 1900, and subsequently in the United States. As a result, certain observations may be stated. In the first place, the common alfalfa root fungus of Europe (*Rhizoctonia Medicaginis*) is the same as the European root fungus of asparagus (*Asparagus officinalis*). This species also occurs less frequently upon the sugar beet (*Beta vulgaris*), and, doubtless, upon other cultivated and wild plants. The fungus appears upon the root as a close weft of violet-colored hyphæ (Fig. 239), composed of cells more or less uniform in diameter, filamentous, branched, but without a particularly characteristic type of branching. Morphologically, it bears no resemblance to the sterile stage of *Corticium vagum*, above referred to, that is, the form causing the rot of the crocus, and a similar disease of the carrot, etc., in Europe, the rot of beets, stem rot of carnations, certain damping-off diseases, etc., in America.

Rhizoctonia Medicaginis is not common in America so far as can be ascertained. In Europe it is one of the most destructive

of the clover diseases and frequently becomes epidemic in plantations of alfalfa, or lucern, a highly important forage plant of Central Europe. In asparagus growing the losses are also occasionally severe.

An ascomycetous fungus occurring upon the stubble of alfalfa, described as *Leptosphæria circinans* Fckl., has been by some regarded as the perfect stage of *Rhizoctonia Medicaginis*, yet through cultures of ascospores the writer has been unable to produce a mycelium resembling that of the Rhizoctonia. Moreover, the mycelium of the Rhizoctonia has been unusually difficult to propagate in artificial cultures.

XV. ROOT ROT OF COTTON AND ALFALFA

Ozonium omnivorum Shear

ATKINSON, GEO. F. Method for Obtaining Pure Cultures of Pammel's Fungus of Texas Root Rot of Cotton. Bot. Gaz. **18**: 16–19. 1893.
PAMMEL, L. H. Cotton Root Rot. Texas Agl. Exp. Sta. Rept. **2**: 61–86. 1889. (Also published as Bullt. **7**: 1–30. 1889.)
SHEAR, C. L., and MILES, G. F. The Control of Texas Root Rot of Cotton. Bur. Plant Ind., U. S. Dept. Agl. Bullt. **102** (Pt. 5): 39–42. 1907.

In Texas and other neighboring states a serious root rot of cotton (*Gossypium* spp.) and alfalfa (*Medicago sativa*) has been known for a number of years. It is not, however, confined to these hosts, and among cultivated plants the sweet potato (*Ipomœa Batatas*) is also affected. Pammel in 1889 reported it on ten or more deciduous trees and also on a few herbaceous weeds. During the summer of 1901 I found this fungus on twelve different weeds in a single cotton field near Paris, Texas. Since these hosts represent a number of widely separated orders, it is apparent that the fungus is practically unrestricted. It does not, however, seem to occur upon monocotyledonous plants.

Little is known about infection and the progressive stages of the disease. There is apparently very little evidence of the trouble until the plant suddenly wilts and dries up. It would seem that cotton plants are far more commonly killed after some of the bolls begin to mature. Certainly dead stalks become more evident from this time forward. Nevertheless, plants have been killed by the fungus before even any definite flower buds, or squares, have

appeared. An examination of the plant after death shows that all of the smaller roots have been killed, and these readily break off as the plant is pulled from the soil. At this time the main root as well as the fibrous root system is infested with a weft, or with strands, of the dirty yellow or buff-colored fungus.

The mycelium penetrates the bark and also the wood of the roots. It does not, however, extend into the wood far above the surface of the soil. This organism in the United States was first studied by Pammel and provisionally referred by him to the sterile form *Ozonium auricomum* Lk. He seems to have had doubt of the correctness of this reference from the beginning, and Shear now regards this American fungus as one clearly distinct from Link's species, and he has accordingly given it a new specific name, as above.

FIG. 240. *OZONIUM OMNIVORUM* ON ROOTS OF COTTON

This fungus may be grown on cooked potato and other nutrient media, but the organism is none too readily isolated. No spore stage has been found in culture, nor definitely associated with it in the open. A careful study of the organism in the field has given indications, however, that an oidium stage may be developed under certain conditions, and that the organism is probably a Basidiomycete.

It seems that no successful inoculation experiments have been reported with this fungus. During two seasons I attempted to transfer the disease to potted cotton plants in the greenhouse.

Diseased roots of cotton and alfalfa, showing an abundance of the fungus, were placed beneath the soil in contact with the healthy roots of half-grown plants. In every case the fungus failed to spread, and after a few months seemed to be dead. These experiments, however, were merely preliminary, and the conditions under which the tests were made could not be considered satisfactory.

Control measures. Control measures, according to Shear, should concern themselves primarily with proper aëration of the soil, especially deep preparation and as close cultivation as may be compatible with other requirements. Fall plowing, under circumstances where this can be practiced without injury to the land, is advised. This is particularly applicable when short rotations are impossible. Rotation of crops is especially important. Grain crops and others known to be free from the fungus should alternate with cotton. An application of a fungicide to the soil at the time of planting seems to be neither effective nor practicable.

HOST INDEX OF FUNGOUS DISEASES SPECIALLY DESCRIBED OR CITED

GENERAL INDEX[1]

[1] For common names of host plants and a list of the diseases of any host, see Host Index, page 483.

ANNOUNCEMENTS

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